SILVERWARE SINGULATING

SYSTEM

By

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SYSTEM

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CHAPTER I

INTRODUCTION

Commercial dishwashing operations in places like hospitals, hotels, universities, and other large institutions require manual work that is tedious and repetitive. Typically conducted in hot and humid environments for long durations, such work requires unskilled labor resulting in poor efficiency, increased costs and absenteeism (Nagaraj, 2003; Simon 2005). Automation of dishwashing operations in such commercial establishments holds promise for reduced labor, reduced operating costs and increased productivity (Peddi, 2005). This has prompted research into automation of dishwashing operations to produce high speed handling, inspection, and sorting operations. However, there is presently on the market no cost effective and efficient automatic mechanism for dish pieces and silverware. Complex geometries of silverware present us with an interesting area of research into separation, inspection and sorting.

The present topic has been motivated by a typical commercial dishwashing operation in a private 700 bed hospital in the midwestern U.S (Hashimoto 1995; Nagaraj 2003). This hospital operates 3 two-hour dishwashing shifts daily, each processing up to 700 trays of dishes. Each tray typically consists of four silverware pieces, a spoon, a soup spoon, a fork and a knife, amounting to 2800 silverware pieces a shift and 8400 pieces a day.

1.1 A Brief History

Automation of silverware sorting typically involves the processes of singulation, identification, inspection, sorting, orientation and wrapping (Hashimoto 1995; Peddi 2005; Lolla 2005; Simon 2005). Figure 1.1 represents a block diagram of the process.

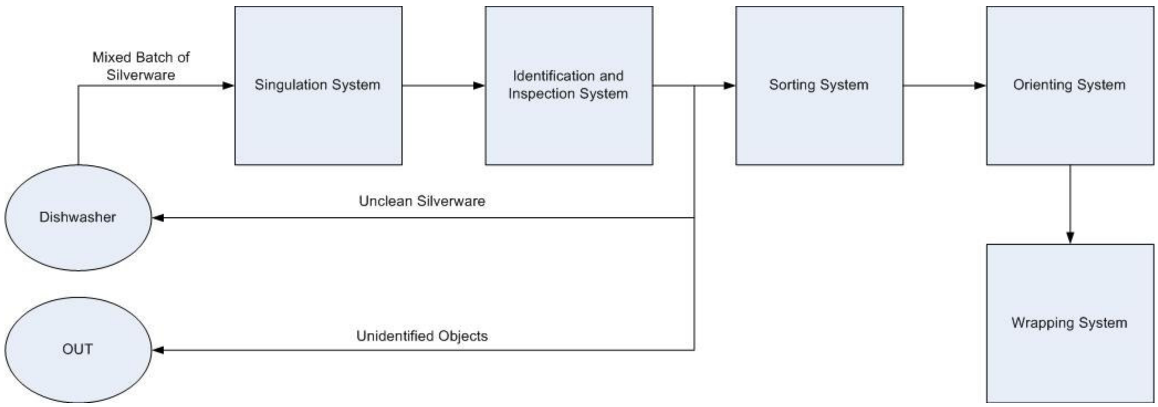


Figure 1.1: Block Diagram of Automation of Silverware Sorting

"Singulation" means 'to single out'. The process of singulation involves separating individual silverware pieces from a mixed batch and placing each piece on a conveyer belt (Hashimoto 1995; Latvala 1999) to subject them to inspection and sorting. A vibrating hopper was designed in conjunction with a magnetic conveyer belt to separate and orient silverware (Hashimoto, 1995). The vibrating mechanism relied on an appropriate selection of frequency and amplitude of the vibration, and was used in conjunction with a specially designed hopper (a device to house the mixed batch of silverware) to deliver silverware in small batches onto a plastic plate covering a magnetic conveyer. The magnetic conveyer was intended to further separate the silverware into single pieces. Small and large batches of mixed silverware, containing 33 and 66 pieces respectively, were used to test the apparatus. The singulating mechanism yielded a maximum efficiency of only 40.7% for separation over a number of trials (Hashimoto, 1995). This presents an opportunity to improve the singulating mechanism.

A silverware identification process was developed by Yeri (2003) using a machine vision system. Nagaraj (2003) developed an orientation and sorting system using signals provided from Yeri's process. Lolla (2005) improved the identification process and developed a machine vision inspection system. Measurements of perimeter, area, and area-moment-of-inertia of silverware pieces were employed to arrive at a fast, reasonably accurate, and efficient algorithm. Using a PC with 1.1 GHz processor and 392 MB RAM, this system processed 55 pieces/min. The vision system identified silverware with 100% accuracy, and produced 87% inspection accuracy for clean silverware and 91% inspection accuracy for dirty silverware (Lolla, 2005).

Peddi (2005) improved on the sorting system developed by Nagaraj (2003), implementing robust techniques to construct a fast sorting and orienting system. Rare earth magnets affixed on a chain conveyer system, together with relay-actuated lifters to remove silverware pieces from the magnets, formed the backbone of this system. An efficient algorithm ensured a reliable method of sorting silverware. This system yielded an efficiency of 97 % for the sorting system and an efficiency of 99.39 % for the orienting system, when processed at speeds of 60 pieces/min (Peddi, 2005).

Zhou (2007) developed image processing techniques to detect dirt, surface anomalies, etc on contoured metal surfaces. Algorithms were developed to address challenges in the form of incomplete images, complex curved surfaces, reflections and shadows (Zhou, 2007). Recognition of incomplete images was achieved using partial and complete pattern matching techniques. Two distinct images of the same object under different lighting conditions at relatively small time intervals were obtained, and image registration and image fusion techniques were performed on them to make up lost information due to specular reflection and shadows. The machine vision system developed by Zhou (2007) processed 12 pieces at an average time of 24 seconds with 100% accuracy in labeling an object clean or dirty. Humans, on average, took 44.6 seconds with 65% accuracy when the objects were placed at arms length, and 26.8 seconds with 72% accuracy when the objects were placed as close as they chose. Zhou's machine vision system developed was robust, fast and accurate (Zhou, 2007).

Simon (2005) developed an automatic mechanism to wrap silverware in a cloth napkin. This process involved manipulation of a restaurant-grade cloth napkin, while developing a mechanism to achieve folds of a napkin about silverware bunches automatically dropped at the unfolded napkin center. Various electromechanical devices and sensors were coordinated using a custom-built controller that employed several integrated microprocessors. The wrapping mechanism yielded an efficiency of 68%, leaving opportunity for improvements. This prior work indicates large need for improvement in three areas:

1. Singulation
2. Napkin Wrapping and
3. Overall system Integration

The area addressed in the work herein is singulation. A patent search, a literature review, and work by Hashimoto (1995) in singulation will be presented in what follows.

1.2 Patent Search and Literature Review

A search through United States patents was conducted using a variety of search terms including “silverware singulation”, “silverware separation”, “flatware singulation”, “flatware separation”, “sort silverware” and “sort flatware”. The search through the U.S. patent classes 209/97, 209/629 and 209/926 (silverware sorter subclass) resulted in eight patents. The first six of these deal with sorting of silverware, and do not separate silverware into individual pieces, which is essential for inspection and identification. The last two patents visually depict singulation, but no commercial applications have been found. A brief summary of these two patents follows, and copies of the complete patents are given in Appendix A.

U.S.Patent 4,954,250 “Flatware Separating Apparatus” Sep 04, 1990, describes the use of a fluid stream to initially separate knives from forks and spoons. Spoons and forks are further separated from one another using custom designed slots for them, respectively. Also, separation into individual pieces using magnets on a cylindrical rotating drum is proposed. This method cannot be useful for our experiment because there is no provision to inspect the silverware. Moreover, the method employed appears to be highly susceptible to jamming of silverware.

U.S.Patent 5,996,809 “Flatware sorting machine” Dec 07, 1999, employs suspended magnets to pick up individual pieces and transport them from the feeder bin to the sorting station. The sorting station contains multiple feed hoppers that are narrow in shape and open ended at the bottom. Jaw members which could be closed and opened in sequentially multiple widths, with the help of cams, were placed below the bottom end of each feed hopper. Located beneath the jaw members is a station to collect handle-up silverware and another to collect handle-down silverware. Each silverware piece is vertically dropped into corresponding narrow feed hopper below it ensuring that the silverware pieces remained vertical. Adjustable width of jaw members at the bottom of each feed hopper ensured that handle-up silverware is collected at one station and handle-down at the other. This apparatus cannot be used for our system because of its relatively higher cost, lack of provision to identify and inspect silverware, and high likelihood of jams because of narrow slots.

1.3 Previous Singulation Work – Hashimoto Singulator

Description: The singulation process attempted by Hashimoto (1995) appeared to offer the best starting point for developing an effective singulator. This process contained a vibrating hopper and a magnetic conveyer. Front and side views of the hopper are shown in Figures 1.2a and 1.2b, respectively. The hopper has parallel vertical side plates attached to a stationary structure through rubber vibration shear mounts (Hashimoto, 1995). Between these parallel side plates, a series of oppositely inclined plates were placed as depicted in Figure 1.2c. The inclinations of these plates were adjustable to enable various configurations during experimentation. An unbalanced rotor vibrating motor made by VIBCO, Model SCR – 200, with adjustable speeds from 900 to 4000 rpm and adjustable centrifugal force up to 200 lbs was used to vibrate the hopper. It was placed on top of the hopper as shown in Figures 1.2a and 1.2b. The hopper with vibrating motor was secured through rubber shear mounts fixed to a stationary frame. The choice of vibration mounts was made using the 1993 product catalog of The Lord Corporation, Erie, PA.

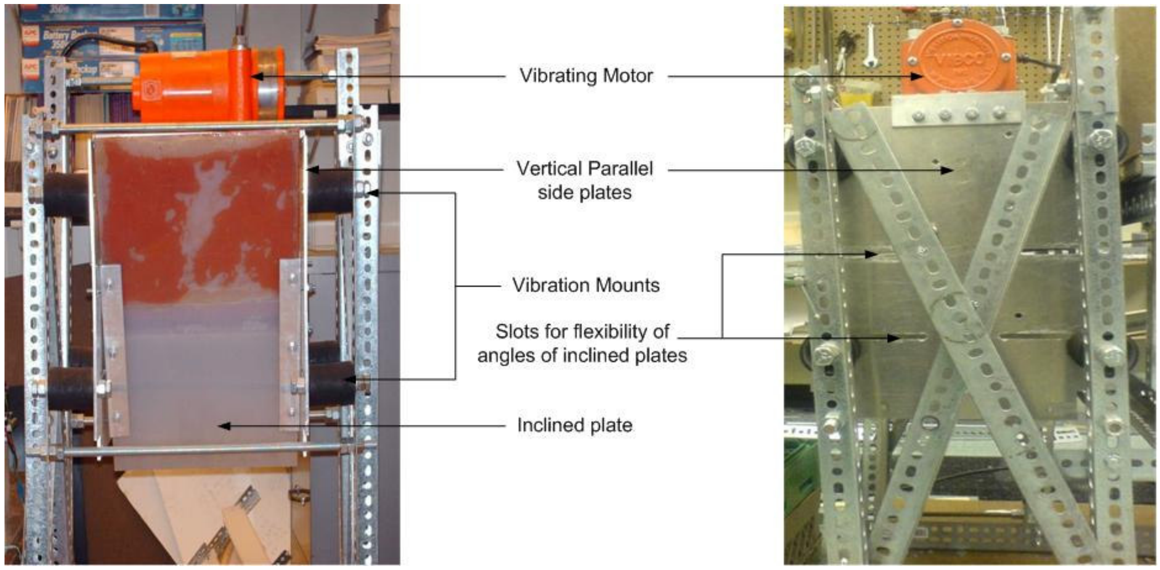


Figure 1.2a: Front View(An Adaptation from Hashimoto's thesis, 1995)

Figure 1.2b: Side View(An Adaptation from Hashimoto's thesis, 1995)

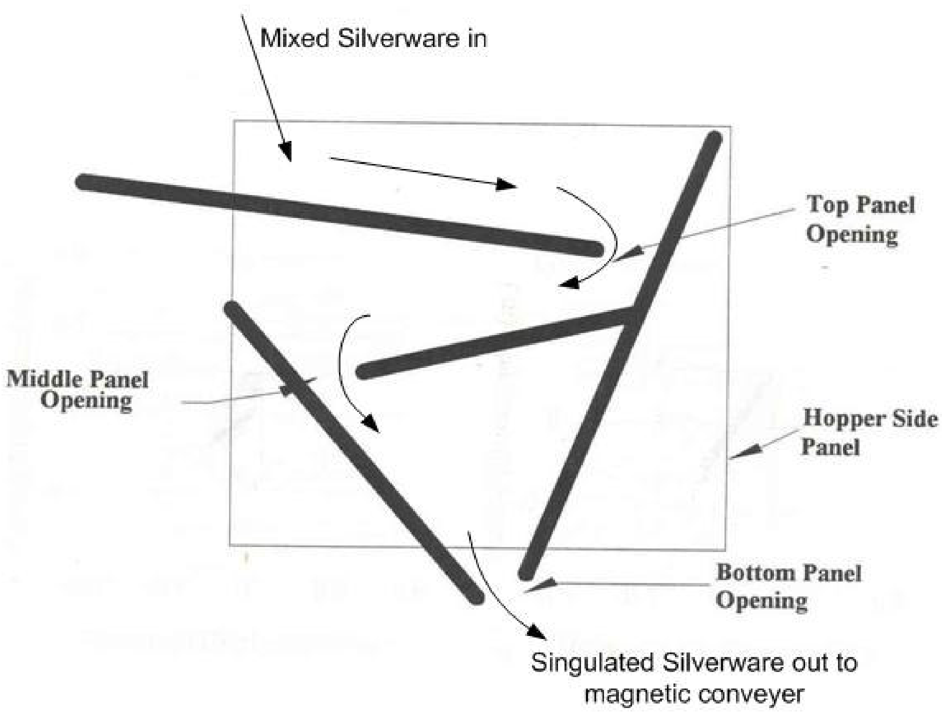


Figure 1.2c: Cross section of hopper (An adaptation from Hashimoto's thesis, 1995)

Hashimoto selected Natural Rubber Medium Sandwich Mount Part No. J-3424-8, made by Lord Corp, with a maximum static load of 33 lbs and a spring rate in shear of 110 lbs/in.

Hashimoto designed a magnetic conveyer using NdFeB rare earth magnets, bought from Bunting Magnetics CO, KS (Catalog No. NEB 2712). The silverware pieces exiting the vibrating hopper landed on a high density polyethylene (HDPE) sheet, and as the magnets moved under the sheet, they attracted and dragged the silverware. A chain drive driven by a variable speed electric motor was used to carry the magnets. A side view and cross sectional side view of the entire apparatus is shown in Figures 1.3a and 1.3b respectively.

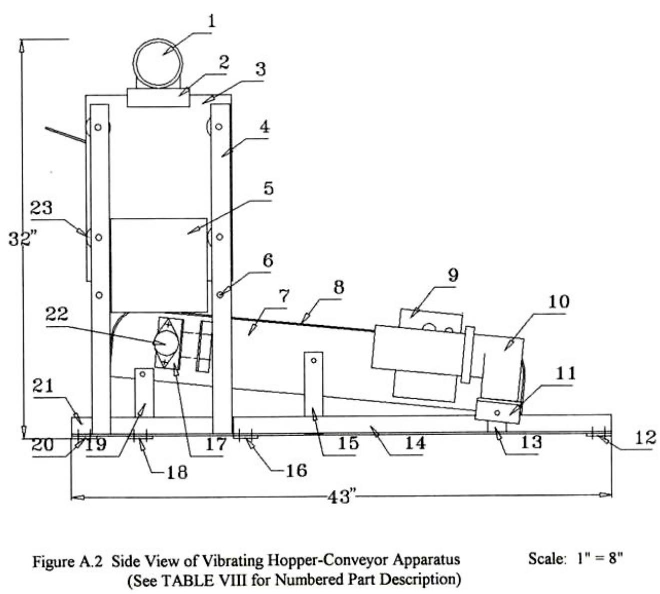


Figure 1.3a: Side View (An Adaptation from Hashimoto's thesis, 1995)*

***-See following page for numbered parts description**

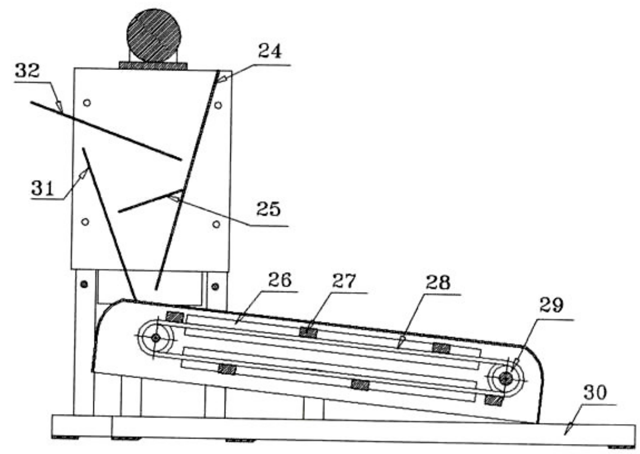


Figure A.3 Cross Sectional Side View of Vibrating Hopper-Conveyor Apparatus Scale: 1" = 8"
(See TABLE VIII for Numbered Part Description)

Figure 1.3b: Cross Sectional Side View (An Adaptation from Hashimoto's thesis, 1995)

Description of the Numbered Parts:

1 VIBCO SCR – 200
2 Vibrator Base
3 Hopper Side Plate
4 0.074" x 1 – ½" x 27" Galvanized Slotted Angle
5 Hopper Side Plastic Cover
6 1" dia. X 19" All Thread Steel Rod, 13 NC Coarse
7 Conveyer Side Plate
8 Conveyer Plastic Cover
9 KB ELECTRONCS Multi-Drive™ Solid State Variable Speed DC Motor Control
10 LEESON DC SUB – FHP Right Angle Gearmotor, Catalog No. 1135045
11 Conveyer Motor Base
12 Vibrating Hopper-Conveyer Apparatus Base Plate(Fourth)
13 0.074" x 1-1/2" x 2-1/4" Galvanized Slotted Angle
14 Conveyer Motor Base Angle
15 0.074" x 1-1/2" x 6-1/2" Galvanized Slotted Angle
16 Vibrating Hopper-Conveyer Apparatus Base Plate(Third)

17 Chain Adjuster

18 Vibrating Hopper-Conveyer Apparatus Base Plate(Second)

19 0.074” x 1-1/2” x 5-1/4” Galvanized Slotted Angle

20 Vibrating Hopper-Conveyer Apparatus Base Plate(First)

21 Hoper Base Angle

22
- 5/8” dia. X 14” long steel shaft
- U.S. TSUBAKI SPROCKET 50B12F – No. 50 5/8” Pitch Finished Bore – 5/8” Bore Dia.
- DAYTON Flange Mount Pillow Block – Light Duty Ball Bearing, Self Aligning – 5/8” Bore Dia.

23 LORD Natural Rubber Medium Sandwich Mount Part No. J -3424 - 8

24 Back Hopper Sloping Panel

25 Center Sloping Hopper Panel

26 SOLIDUR TIVAR ANSI Standard Roller Chain Guide – Profile K No. 50 – 22” Ea.

27 Magnet – Carrying Aluminium Strip

28 U.S. TSUBAKI Standard Attachment Chain No. RS50 – 1 8L WA2, 96 Pitches

29
- 1” dia. X 15” long steel shaft
- U.S. TSUBAKI SPROCKET 50B12F – No. 50 5/8” Pitch Finished Bore – 1” Bore Dia.
- DAYTON Flange Mount Pillow Block – Light Duty Ball Bearing, Self Aligning – 1” Bore Dia.

30 Conveyer Base Angle

31 Front Hopper Sloping Panel

32 Top Feed Hopper Panel

When a mixed batch of silverware is placed in the hopper and the vibrating motor is switched on, the vibration along with the panel-openings slowly start to separate pieces in stages. The pieces move by gravity and vibration to the top panel opening (Figure 1.2c).As the slot width is narrow, only a few silverware pieces fall through the top panel opening, some fall through the middle panel opening, and some through the bottom opening. Once the pieces exit the hopper through the bottom panel opening, they fall onto the HDPE plate covering the magnetic conveyer, which further separates them.

Disadvantages:

- Orientation of a mixed batch of silverware exiting an automatic commercial dishwasher is random. The slots in the hopper either provide insufficient clearance for effective separation of pieces, or cause jams.
- An effective single set of slot widths could not be found, owing to the indeterminate nature of the orientation of silverware. Either the slots were too narrow or they were too wide. This resulted in an uneven distribution and/or jamming of silverware leading to inconsistency in performance.
- The process lacked a controlling device which might have provided more consistency for separation of silverware.
- The dragging of silverware over the HDPE sheet using magnets placed underneath always resulted in a chattering motion of the silverware pieces, making it difficult to identify and inspect silverware using machine vision.

1.4 Objective

The objective of this thesis is to design, construct and test an improved and more efficient mechanism to singulate silverware pieces. A mixed batch of silverware will need to be processed, and the silverware pieces need to be separated individually at a minimum of 30 pieces/min. The current manual labor processing rate determined from measurements at a 700 bed hospital in Tulsa, OK is 2400 pieces in a two hour shift, yielding 20 pieces/min.

CHAPTER II

INITIAL EXPERIMENTS

Singulation of silverware is a complex problem, although it manifests itself as a simple challenge to overcome. As with many new experiments undertaken to address a specific target, various design factors influencing the outcome must be considered. Several different approaches were tried and their inadequacies are explained. The final section of this chapter discusses the outcomes of these initial experimentations and leads to a proposed method to achieve the desired target.

2.1 Initial Design Considerations

Initial design factors have been broadly classified into two categories based on two types of constraints. Some of the factors mentioned below may very well apply to both categories of constraints.

1. <u>Process Dependent Constraints:</u> Process dependent constraints are constraints that can be attributed to the inherent nature of singulation itself. Irrespective of the method chosen to implement singulation, these constraints are native to the actual process and its requirements. These include: The random nature of mixed silverware; the size and configuration of the experimental test rig required to accommodate a specified number of silverware pieces; the material of which

silverware is made; clustering and\or cluttering of silverware pieces; compatibility with other operations of the silverware handling process; efficiency; and throughput.

2. Method Dependent Constraints: When solving a specific problem, there may exist more than one method to achieve the desired result, and this is certainly true for silverware singulation. Constraints specific to the method alone are termed method dependent constraints, and these include, method of separation; material properties of the test equipment, and type and efficiency of sensing element.

On the basis of the processing requirements indicated in Section 1.4, a plan to design and build an experimental test rig to singulate a batch size of 400 silverware pieces was deemed large enough to simulate commercial dishwashing operations. A set of 100 spoons, 100 soupspoons, 100 knives and 100 forks was used to constitute the 400 pieces. The planned test rig was required to process this mixed batch of 400 pieces of randomly oriented silverware, producing singulated pieces at a throughput of 30 pieces / min with accuracy of 90% or better.

2.1.1 Silverware Material

Commercial silverware is generally made from stainless steel. Stainless steel contains a minimum of 11.5% of Chromium that aids in prevention of rusting, tarnishing and corrosion. Stainless steels can be classified into austenitic, martensitic, ferritic and duplex types based on their chemical composition and crystalline structure.

A typical composition of 18% chromium and 10% nickel, commonly known as 18/10 stainless steel is often used to make silverware. A composition of 18% chromium and 8%

nickel is also used extensively and is known as 18/8 stainless steel. The other available types of stainless steel used in silverware are 18/0(with 18% chromium and 0% nickel), 420 and 440. 18/10(type 316) and 18/8(type 304) steels belong to austenitic type, 18/0 to martensitic type and 420 and 440 to ferritic type stainless steels respectively.

Austenitic or 300 series of stainless steels contain a minimum of 16% chromium and small quantities of manganese and nickel and have a face centered cubic lattice structure. Austenitic stainless steels are effectively non magnetic in annealed condition. The higher the presence of nickel the more difficult it is to magnetize. In comparison, 18/0, 420 and 440 grades have body centered cubic lattice structure and are magnetic.

As discussed in the previous chapter, silverware singulation forms a part of a larger apparatus to automate identification, inspection, sorting, and wrapping of silverware pieces. Silverware sorting apparatus (Peddi, 2005) uses NdFeB (Neodymium, Iron, Boron) magnets to successfully sort pieces according to type and orientation. To ensure compatibility with such an apparatus, silverware pieces must be magnetic. The silverware used in this experiment have been made from 18/0 stainless steel and are magnetic, and were purchased from Market Source Inc. (http://www.marketsourceonline.com), Oklahoma City, model nos. FL – RIM – 1(spoon); FL – RIM – 2 (Soupspoon); FL – RIM – 5 (Fork); and FL – RIM – 7 (Butter knife). Material vendor quote is given in Appendix - B.

2.1.2 Size, Shape and Weight of Silverware

Figures 2.2 – 2.5 are photographs of our silverware pieces along with their respective dimensions, and Table 2.1 shows their corresponding weights.

Figure 2.1: Knife and its Dimensions

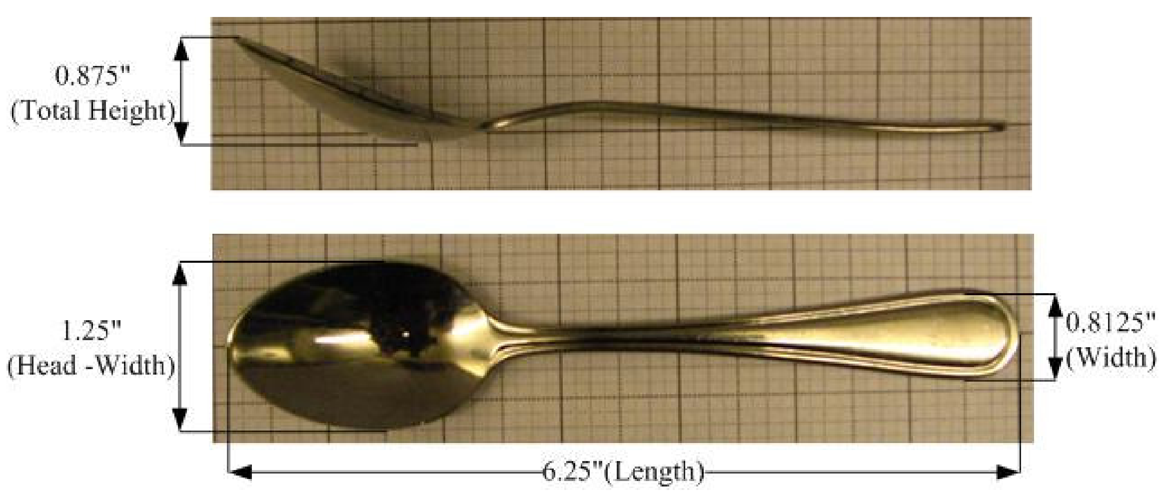


Figure 2.2: Spoon and its Dimensions

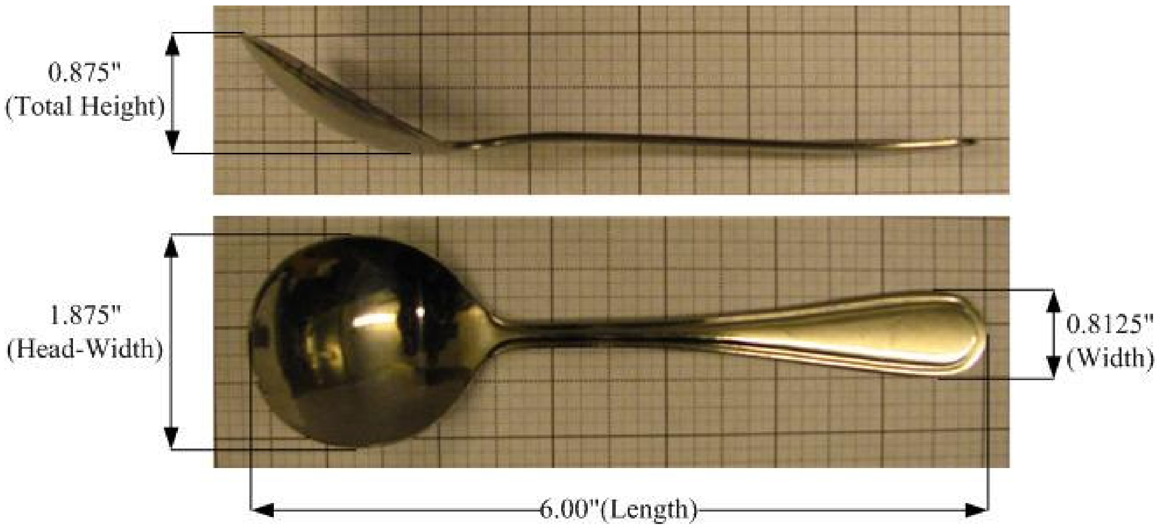


Figure 2.3: Soupspoon and its Dimensions

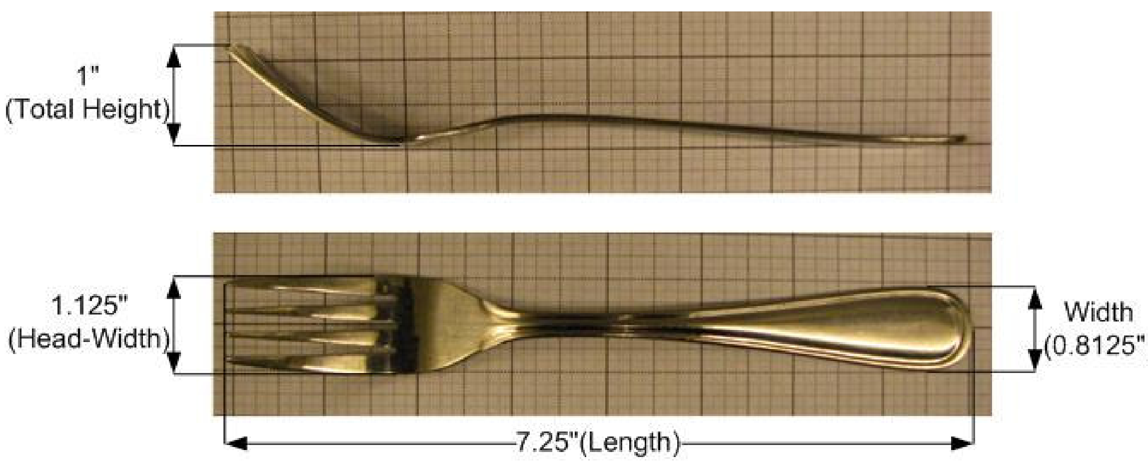


Figure 2.4: Fork and its Dimensions

Table 2.1: Weight of Each Type of Silverware

S.No	Type of Silverware	Weight(oz)
1	Knife	2.7
2	Spoon	1.3
3	Soupspoon	1.3
4	Fork	1.4

<u>Size and Weight:</u> Size, weight and irregular shapes of silverware pieces significantly influence Singulation process. Due to this, a Singulation process must be designed to prevent any jamming of silverware pieces at any point of the experiment. Any gaps or slots required by the experimental apparatus ("rig") must be made large enough to accommodate any silverware piece in any possible orientation. As can be observed from Figure 2.2 and Table 2.1, the knife is the longest and heaviest of silverware pieces. The length of the knife plays a decisive role in determining a few dimensions at multiple locations in the planned test rig. It is evident from Table 2.1 that the weight of each knife is equal to or greater than the combination of weights of any two other types of silverware. The presence of a mixed batch of silverware at the beginning of the experiment, together with the high weight of the knife place a severe constraint on using weight as a distinguishing factor to separate pieces. An important aspect to note here is that the combined weight of 400 silverware pieces is approximately 42 lbs. The test rig should be designed to support this weight and withstand the rigors of experimentation.

<u>Shape:</u> The teeth of the fork enable it to easily entangle it with other silverware pieces, as seen in Figure 2.6, making it difficult to separate such configurations. Furthermore, the cup shaped head of the spoon and soupspoon and the curved pronged head of fork, place a constraint on the type of sensors required for detecting the presence of silverware at various places in the test rig.

Figure 2.5: Various Configurations of Entangled Forks

2.1.3 Random Nature of the Experiment

At the beginning of each experiment, when a batch of 400 mixed silverware pieces is collected, they become distributed in an irregular manner. Examples of three possible configurations are shown in Figure 2.6 on the following page.

At times, silverware pieces can spread over multiple heaps, while at other times they can form several small clusters within one big heap. Additional cluttering of silverware may take place within these clusters. There are numerous possibilities. In addition to the changeable nature of the stacking of the batch, the geometries of silverware used in the experiment present further complications. These unpredictable distributions at the start of every new experiment necessitates a processing technique that produces results invariant

Configuration 'A' Configuration 'B' Configuration 'C'

Figure 2.6: Distribution of 400 pieces of Silverware

Configuration 'A': Bunch up in a Single Heap

Configuration 'B': Distribute Evenly and Spread Out

Configuration 'C': Bunch up in 2 Heaps with a Small Gap in Between

with input distributions. Also, it was assumed that the probability of successfully singulating from smaller batches is greater than that of singulating from a batch of 400 pieces. Hence, it was decided that the process of singulation should be sub-divided into two stages:

1. **Stage-01:** To divide the batch of 400 silverware pieces into smaller batches of approximately 20 pieces each.
2. **Stage-02:** To singulate silverware pieces from these smaller batches of 20 pieces.

2.2 Initial Methods and their Disadvantages

Prior experimentation with Hashimoto's rig (Hashimoto, 1995) demonstrated that vibration as a standalone method cannot efficiently singulate silverware. Vibration aids in spreading the distribution of the silverware and thereby assists the process of singulation. But, due to the inherent randomness at the beginning of each experiment, vibration alone yielded unpredictable and inconsistent results. Hence, other alternatives had to be considered. We determined that the magnetic susceptibility of silverware provided an interesting property that should be investigated. All the permanent magnets used for experimentation in the various methods discussed below were selected from NdFeB magnets due to their superior holding strength.

As defined on the previous page, Stage-01 did not have a specific target in that it was required to divide 400 pieces into smaller batches of "approximately" 20 pieces. It was not necessary that exactly 20 pieces were contained in each batch, whereas Stage-02 had a specific and well defined target of picking single pieces. Moreover, at that point of time, only 80 silverware pieces were readily available in the lab. Before proceeding ahead to experiment with 400 silverware pieces, it appeared reasonable to test the readily available pieces in the lab. Therefore, we decided to investigate into finding a solution for Stage-02 before initiating experimentations for Stage-01.

2.2.1 Stage-02: Use of Magnets to Singulate Silverware

The fundamental idea in using magnets was that, when brought into close contact with silverware, magnets would attract silverware pieces, causing them to initially separate and finally singulate. Various bar and spherical NdFeB magnets of varying sizes were used in experiments to determine the best size, magnetic force, and area of contact with silverware for the purpose of singulation. A hemispherical magnet of ½" diameter [Lee Valley(www.leevalley.com), Item # 99K38.51], shown in Figure 2.7 below, was preferred over other shapes and sizes due to the following experimental observations:

- The round exterior of hemispherical magnets had point contact with silverware and hence displayed higher efficiency at picking single pieces.
- The flat exteriors at the other end of the magnets provided an easy base for the magnets to be mounted.

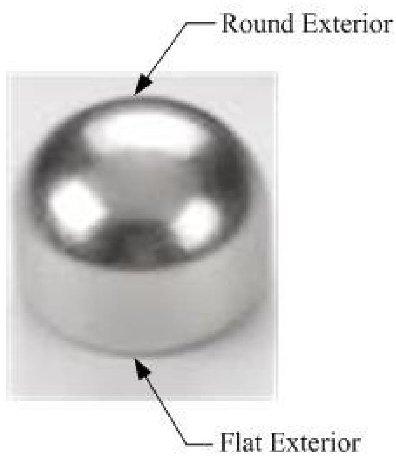


Figure 2.7: $\frac{1}{2}$" Dia Hemi-spherical Magnet

The following two methods were attempted using hemispherical magnets:

1. Method 01: Singulation of Silverware using Hemi-spherical magnets from Above.
2. Method 02: Singulation of Silverware using Hemi-spherical magnets from Below.

<u>Method 01: Singulation of Silverware using Hemi-spherical Magnets from Above</u>

The experimental setup for this method included a bin to house silverware, hemi-spherical magnets, a belt drive, a scrapper, and a supporting structure depicted in Figure 2.8. Dimensions of the bin were 18" x 12" x 1", and the thickness of the base of the bin was $\frac{1}{16}$". Twenty pieces of silverware were placed at the center of the bin. A side stock flat leather belt [Mcmaster-Carr, Item # 6078K11] of width 1", thickness $\frac{5}{32}$" was used for the belt drive, and hemi-spherical magnets were mounted on top of this belt at equidistant spaces of 5" apart. The bore and outside diameter of each pulley [Mcmaster-Carr, Item # 6235K76] is $\frac{1}{2}$" and $4\frac{1}{2}$" respectively, and the distance between the pulleys is 30". A bin was placed at one end of the belt and a scrapper at the opposite end of the belt. A rudimentary sketch of the setup is shown in Figure 2.8.

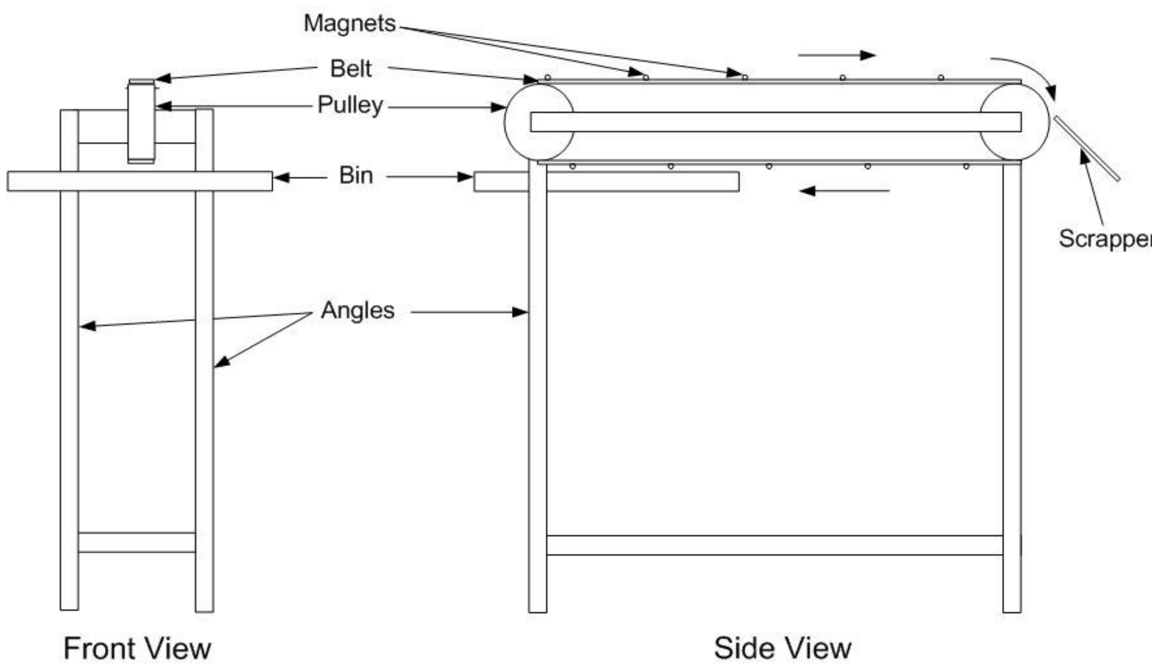


Figure 2.8: Method-01: Rear View and Side View of Singulation using Hemi-Spherical Magnets from Above

For initial testing purposes, the belt drive was hand-cranked to rotate it and move the belt with magnets. It was expected that as the belt moved across the bin, the magnets would come into contact with the silverware placed in the bin and pick individual pieces of silverware. Further, it was expected that each piece of silverware that was picked and held by the magnet would be scrapped off at the other end with the help of the scrapper.

Pros:

1. The initial results were promising in that the individual silverware pieces were picked up by the magnets as desired at the bin-end and were scrapped off at the opposite end.
2. This approach laid out an initial framework to experiment more with magnets, probe deeper into the design aspects and fine tune the system so that it could consistently pick single pieces at high efficiency and desired throughput.

Cons:

1. Due to the configuration of this setup, the shape and size of the silverware bin was inadequate.
2. The magnets picked more than a single piece on a consistent basis in spite of having point contact with silverware pieces.
3. During the course of the experiment, as the number of pieces decreased in the bin, the gap between the magnets and silverware increased. This continued until the gap was too large for the magnets to pick up pieces left in the bin.
4. In order to offset the gap and continue to pick pieces, we considered the following:
    a. Sensor feedback to monitor the gap between the magnets and silverware, followed by corrective action to automatically decrease the gap. The metallic reflective surface, the contoured shapes of spoon and soupspoon, and the uneven surface of the batch hindered the selection of a good, economical sensor that could have provided the required feedback.

b. Use customized miniature electro magnets to control the magnetism and thereby continue to pick pieces. The prospect of mounting electromagnets and their associated wiring on a belt drive complicated the implementation of this idea. Hence, this idea was discarded.

Method 02: Singulation of silverware using Hemi-Spherical Magnets from Below

A second approach was attempted, similar to that in Method-01, except that magnets approached silverware from underneath the bin as shown in Figure 2.9. The belt and bin were arranged in a manner such that the magnets slid underneath the base of the bin resulting in silverware getting dragged across the surface of the base under the influence of the magnets beneath.

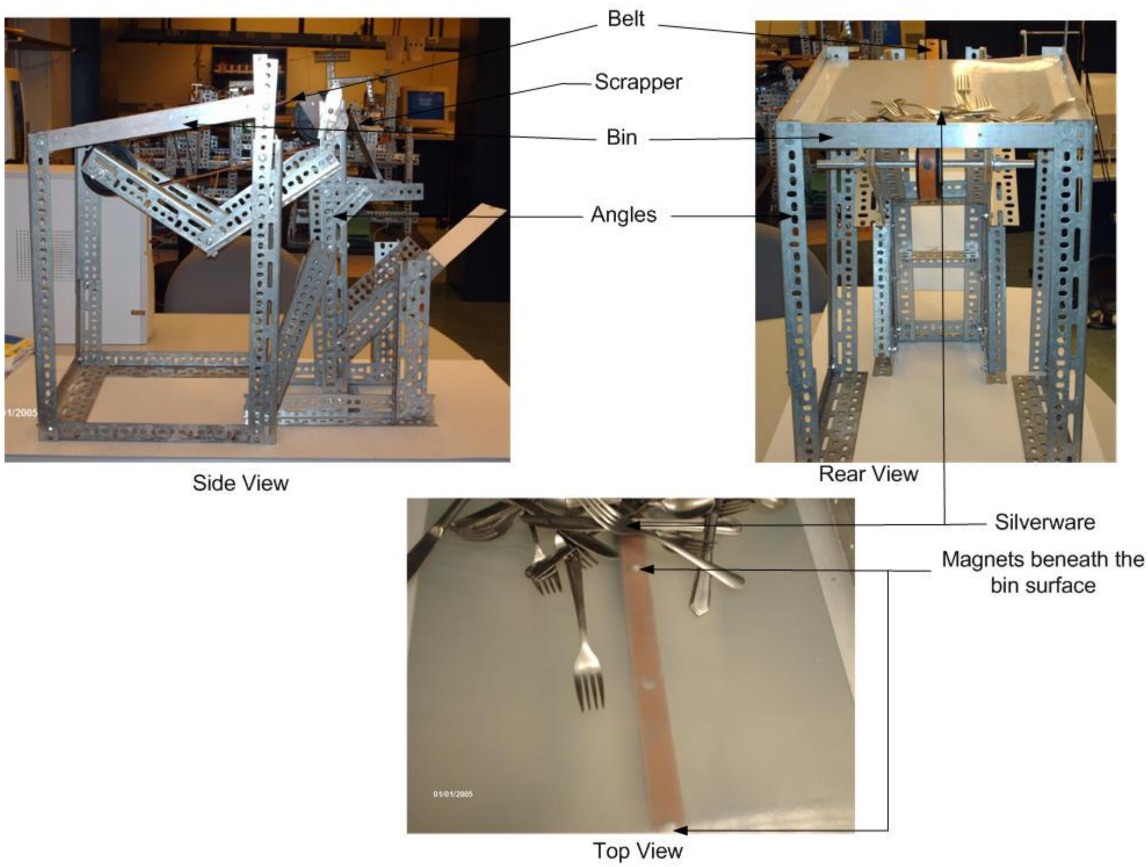


Figure 2.9: Method-02: Side View, Rear View and Top View of Singulation using Hemi-Spherical Magnets from Below

Pros:

1. Method-02 eliminated the problem of varying gap present in Method-01. The distance between magnets and silverware was not a function of the number of pieces present in the bin.
2. The sheet material of the base of the bin served to act as a small gap between the magnets and silverware pieces. This decreased the probability of the magnets holding onto multiple pieces and caused the singulating efficiency to increase considerably as compared to the magnets coming into direct contact with silverware.

Cons:

1. The surface characteristics of the base of the bin such as thickness, surface roughness and rigidity determined the singulating efficiency of this approach. Depending on the surface material, the performance varied widely.
2. A new constraint had to be applied to the distance between adjacent magnets in this approach. This distance had to be greater than the longest piece of silverware. If the distance was less than this length, it caused adjacent magnets to hold on to the same piece (typically knife). The magnet at the front caused the piece to be dragged forward while the magnet at the rear tended to hold it back. This resulted in the work done by adjacent magnets to be counterproductive to each other and thereby cause the singulating efficiency to decrease.

In order to maintain high singulating efficiency and to address the distance between adjacent magnets, every alternate magnet was removed from the belt causing the distance between adjacent magnets to rise to 10”. This method showed sufficient promise to explore further and improve overall performance by selecting an appropriate sheet (base).

2.2.2 Selection of a Motor for the Belt Drive

Prior to experimenting with various sheet materials, we decided that a motor to rotate the belt would be a better actuator than hand cranking, which had been previously employed. While we could have selected a motor size using mathematical modeling, we found it faster to test by trial and error. A 24V DC gear motor with a torque rating of 11.5 Nm (≅ 101.8 lb-in) was purchased from E-bay. The required vendor information [wondermotor.com], speed-torque curve for the motor (curve shown for a 13V motor as corresponding values for a 24V motor are not supplied by the vendor) and a schematic with dimensions can be found in Appendix - D, and is shown in Figure 2.10.

This is a reversible gear motor and its speed can be varied by varying the voltage. The advantage of using this motor is that due to its high torque capabilities, the belt could be rotated at both low and high speeds while still being able to attract and drag silverware pieces across the duck cloth.

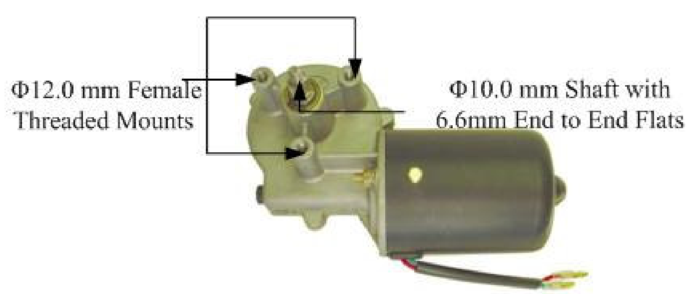


Figure 2.10: 24V DC Variable Speed Reversible Gear Motor

Table 2.2 below shows the relationship between the speed of the belt and corresponding number of magnets that pass through a given point per minute. This table helps in determining the minimum speed required to run the belt at which the required throughput of 30 pieces/min can be met.

Table 2.2: Relationship between Voltage, Number of Magnets/min and Belt Speed (in/min)

S.No	Voltage Applied to the Motor(V)	Number of Magnets / min	Belt Speed (in/min)
1	15	43	430
2	18	52	520
3	21	59	590
4	24	67	670
5	27	76	760

2.2.3 Experimentation to Select Sheet Material

Several different materials for the sheet were tried to determine the best singulating performance. Some of these sheets exhibiting promising performance were used extensively, and their individual singulation performances are described below. It should be noted that the assessment of performance of sheets was based entirely on visual inspection of the number of silverware pieces successfully singulated over a large number of trials. It was assumed that friction of the surface of the sheet material, rigidity of the material, magnetic permeability, and cross-sectional thickness were some of the factors that contributed to singulation performance. Exact determination of the amount and nature of contribution of each factor was beyond the scope of this thesis.

– **Polypropylene $\frac{3}{32}$" thick sheet:** Polypropylene sheet provided reasonably fair singulation results at low belt speeds (corresponding to 20 magnets/min passing under the sheet). At relatively higher belt speeds (corresponding to 35 magnets/min), silverware pieces, and specifically forks, were not picked regularly and therefore singulating efficiency decreased considerably. Fork heads are curved in one dimension only, and this caused forks to have an “area contact” with the sheet thereby placing a constraint on the movement of forks. Moreover, fork teeth are thin and pronged in shape. Accordingly, when a fork is singulated with its head attracted by the magnet, the handle of the fork can be in the air, and the moment of this handle acts against the attractive force of the magnet underneath. As shown in Figure 2.11, any surface anomalies or deformations cause the teeth of the fork to lose its contact with the magnet underneath causing the fork to fall back. On the other hand, spoons and soupspoons have their heads curved in two dimensions causing them to have a point contact with the sheet. Therefore, despite the handle moment acting on spoons and soupspoons and any surface anomalies, the curvature in second dimension helped in movement of spoons and soupspoons, sustaining the magnetic contact and preserving the attractive force of the magnet. A comparison of the two cases is shown in Figure 2.11. Overall, singulating efficiency at required speeds was poor and hence polypropylene at $\frac{3}{32}$” thickness could not be used.

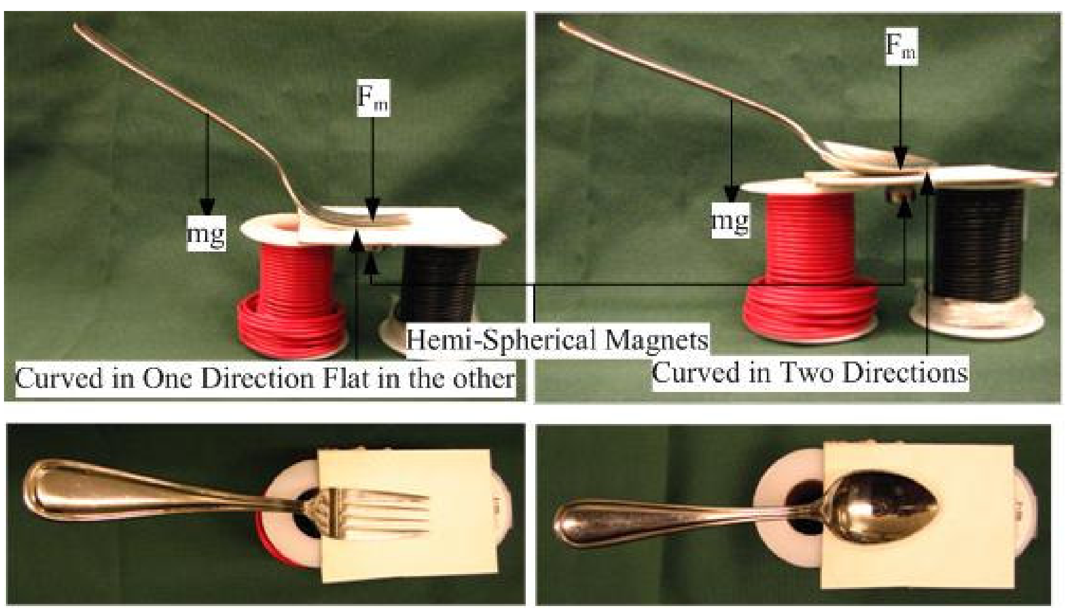


Figure 2.11: Comparison of Fork and Spoon when Attracted at its Head

- **Polypropylene $\frac{1}{16}$" thick sheet:** Polypropylene $\frac{1}{16}$" sheet provided better results as compared to $\frac{3}{32}$" sheet, but only marginally better in singulating efficiency. Also, whenever the size of the batch was greater than 20 pieces, due to the additional weight of the silverware in the pile on the pieces at the sheet surface, the magnets were unable to attract pieces sufficiently regularly and singulate efficiently at the required rate.
- **Nylon 0.05" thick sheet:** This sheet provided very poor singulation performance, in spite of its small thickness. Based on observation of its behavioral characteristics, high friction and rigidity of the sheet appeared to be the contributing factors. Hence, this sheet was discarded.
- **Acrylic 0.06" thick sheet:** Singulation performance using acrylic sheet was better than nylon, but was still unsatisfactory, and below that for PE. The pieces were dropped regularly during the course of being dragged by the magnets underneath. Based on observation of its behavioral characteristics, it appeared that the friction due to the ribbed nature of the surface and low magnetic attraction across the sheet were major factors in its non performance.
- **Polyethylene (UHMW) $\frac{1}{16}$" thick sheet:** Singulation performance using this sheet was poor due to the thickness of this sheet and friction characteristics of the surface.
- **Teflon $\frac{1}{32}$" thick sheet:** This sheet displayed relatively good singulation performance compared to the other sheets described above. Due to the very smooth nature of the surface of this sheet, and corresponding low friction between

sheet and silverware, good performance was obtained even when 25 pieces were placed on the sheet. On the other hand, occasionally multiple pieces of silverware pieces were dragged by a single magnet. Moreover, after substantive experimentation, the sheet became

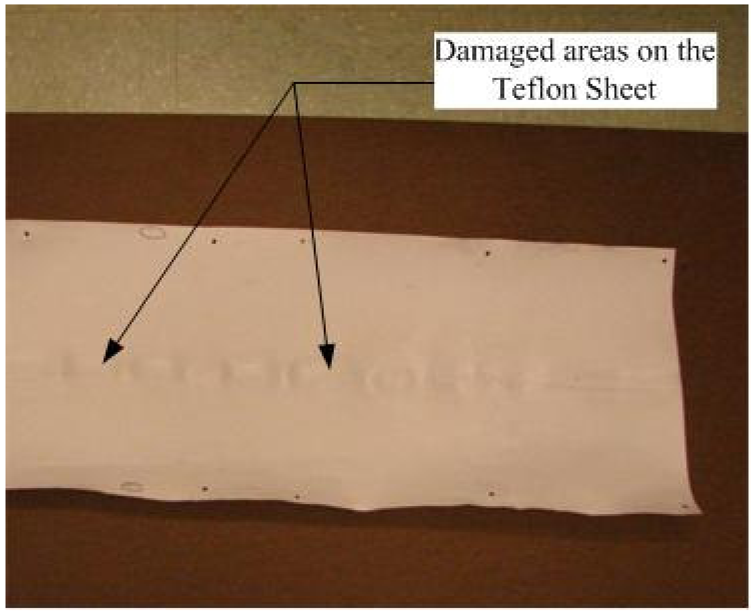


Figure 2.12: Damaged Teflon Sheet

rigid and damaged in areas where silverware pieces were dragged repeatedly, resulting in reduced efficiency. In spite of these mitigating factors, we felt the good results obtained were sufficient to place this sheet as a possible backup in the event of non availability of a suitable alternative. Figure 2.12 shows the damaged areas on the sheet after it was removed from experimentation.

– **Cardboard Sheets With and Without Smooth Finish:** Performance of cardboard sheets was comparable to that of Teflon sheet, and at times was better. Due to fragility of the cardboard material for the nature of this experiment, cardboard without a smooth finish offered more friction, lower performance and durability. Cardboard sheets with smooth finish provided better results to sheets without. Although the smooth-finished sheet provided excellent results, the frequent damage caused to the sheet during experimentation did not make it a viable alternative on a regular basis.

At this stage of experimentation, it was decided that cloth materials should be included for testing purposes. The advantages of using cloth are:

- Cloth is not rigid. This factor might aid in preserving better magnetic contact in the case of forks;
- Thickness of the cross section can be very small, unlike the various semi-rigid sheets used earlier, allowing greater magnetic force on the silverware.

The associated challenges are to find:

- A durable material that can stand the rigor of experimentation.
- A material with low friction for silverware pieces.

– **Leather cloth:** In spite of being only marginally thicker than paper and possessing good durability quality, leather cloth displayed very poor performance with hardly any piece getting singulated. Silverware repeatedly failed to move on the sheet despite several magnets passing underneath. Hence this cloth was discarded

– **Duck cloth:** Duck cloth performance was the best of all sheet material tried. Despite batches of 25 pieces and at times exceeding 30 pieces on the sheet, pieces were singulated very efficiently. Also, at higher belt speeds (corresponding to as high as 65 magnets / min), magnets continued to pick up silverware pieces on a regular basis and at high efficiency. However, it lacked durability, and did not last as long as polyethylene sheets. However, due to the fact that that duck cloth proved to be the best performer among many, it was chosen as a suitable material for future experiments.

Also, a number of other materials, which were not used as extensively and hence not described above, have been tried to find the best sheet for future experiments. However, since silverware pieces were being successfully singulated at required throughput and efficiency with duck cloth, it was deemed that a solution had been found for Stage-02 and trials were initiated at finding a solution for Stage-01.

2.2.4 Stage-01: Separation of Silverware into Smaller Batches

In order to begin experimentations for Stage-01, 400 silverware pieces were purchased with model numbers specified in Section 2.1.1.

Use of Block Magnets to Separate Silverware: Use of block magnets was based on a similar concept to that in stage-02 and hence required the same testing apparatus that was used for stage-02. In order to separate silverware into smaller batches in stage-01, use of block magnets [www.magnet4less.com # NB024-42NM] in the place of hemi-spherical magnets was proposed. The rated pull force for these magnets was 72 lbs. An example block magnet is shown in Figure 2.13.

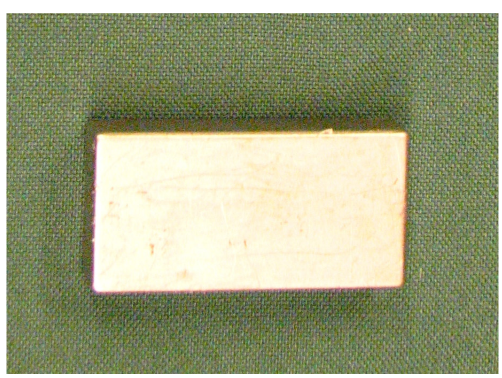


Figure 2.13: An Example 2" x 1" x $\frac{1}{2}$" Block Magnet

Also, duck cloth was replaced by $\frac{3}{32}$" polyethylene sheet due to the additional weight of the 400 pieces of silverware required for stage-01. Before experimenting with the full batch of 400 pieces, a partial batch of 80 pieces was used to test the applicability of Stage-02 method to Stage-01. 80 silverware pieces were placed in the bin. Hemispherical magnets were replaced by larger rectangular NdFeB block magnets of dimensions 2" x 1" x $\frac{1}{2}$" underneath the sheet. These rectangular magnets were then dragged across the sheet by hand. Despite the magnetic force being much greater in this case than in stage-02, the presence of a large batch of silverware hindered the magnets from attracting any pieces. During a number of trials, the magnets displayed inconsistent separating efficiency resulting in poor throughput. Also, this experiment demonstrated that the number of pieces attracted to a magnet is not necessarily proportional to the size of magnet. The bending stress induced in the sheet due to the weight of the silverware caused non-uniform gaps to be present between the magnets and silverware. Due to these above observations, this method was discarded.

Use of an Electromagnet to separate silverware: After the initial experiment with block magnets failed to show promising results, use of an electromagnet was proposed. The advantage of using an electromagnet over a permanent magnet is that a variable magnetic force can be produced by varying the current to the electromagnet. This provides an opportunity to experiment and estimate the magnetic field strength required to attract, hold, lift and separate small batches of silverware.

Electromagnets can be broadly classified into AC electromagnets and DC electromagnets depending on the source of electrical power. AC electromagnets are typically used mainly in demagnetization, and vibration applications. DC electromagnets are used mainly in holding, and lifting applications.

Commercially available permanent magnets and electromagnets are rated to lift a specified weight that is based on measuring the actual force required to separate a 2” thick mild steel plate from the magnet at no air gap. Depending on the material composition of the object to be lifted, its cross section thickness, its magnet-to-metal contact area, the air gap between the magnet and the object to be lifted, the lifting capabilities may largely vary.

In silverware singulation, the cross sectional thicknesses of silverware pieces are substantially less than 2”, the material is not mild steel, the area of contact with the magnet is quite small by comparison, and the air gap can only be approximated. Due to these factors the actual lifting capability is virtually unknown until experimentation is done, and therefore choosing a strong electromagnet that far exceeds the actual lifting requirements provides the flexibility required to increase or decrease the applied magnetic field as necessary.

For reasons described above, for testing purposes, a 24V DC electromagnet [Coil Technologies, Part # E – 0379 – 4] was purchased, the dimensions of which are shown in Figure 2.14 on the following page. It weighs approximately at 6 lbs and its specifications are:

- Lift 962 lbs at 24V DC and 879 lbs at 12v DC.
- Work at 50% duty cycle at 24V DC, and continuous duty cycle at voltages up to 10v DC.

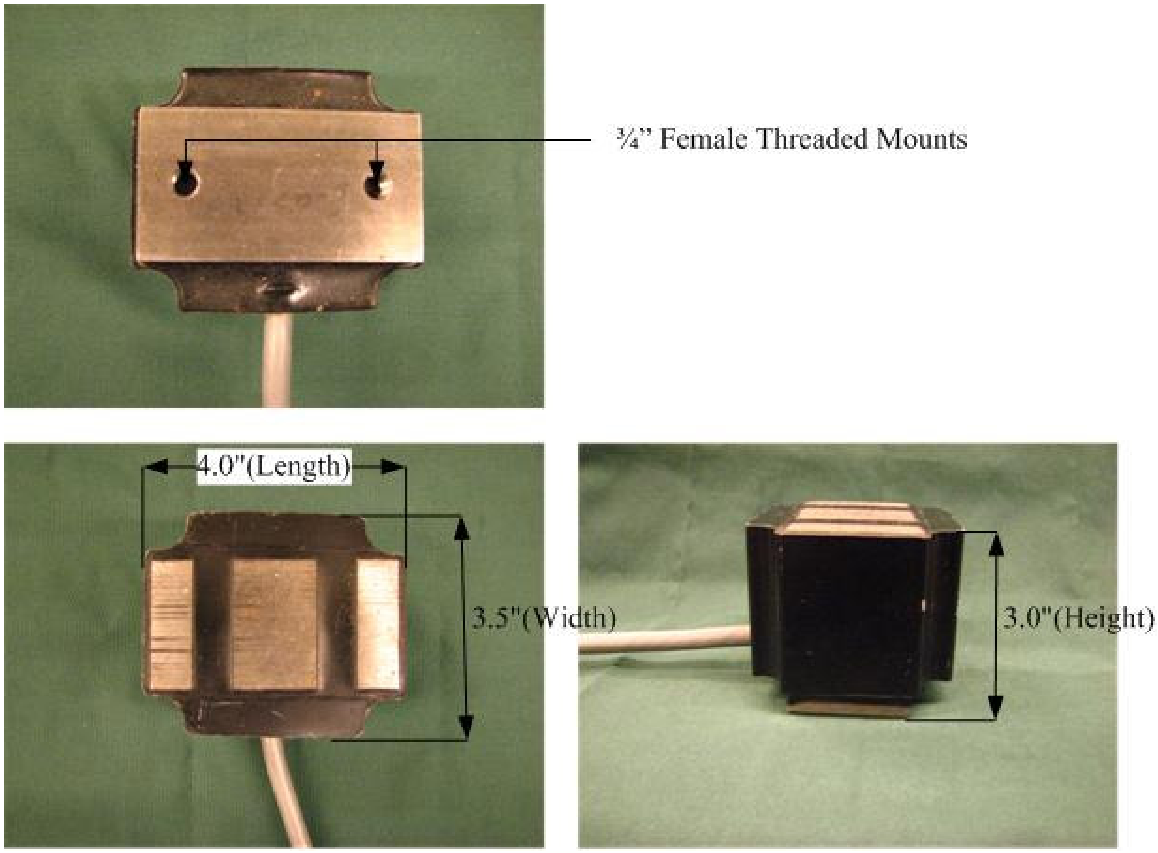


Figure 2.14: 24V DC Electromagnet and its Dimensions

Figure 2.15: Bin Stacked with Silverware Pieces

To contain silverware pieces, a bin shown in Figure 2.15 was designed such that its length and width progressively narrow from top of the bin measuring, 18” x 18”, to the bottom of the bin, 10” x 10”. The height of the bin is 8”. The length of the base at 10” is slightly greater than the length of the knife to prevent knives from getting stuck at any place in the bin and to be able to accommodate knives in horizontal positions at base.

Also, narrowing the base to 10” increases the probability of singulating the few silverware pieces remaining at the bottom of the bin after the pieces higher in the bin have been removed. Figure 2.15 shows an example of silverware pieces getting stacked in the bin. The underlying idea behind this experiment is to lower the electromagnet to the top of the silverware are in the bin using an actuator, followed by switching on the electromagnet to attract the top layer of silverware in the vicinity of the electromagnet. The attracted pieces are then lifted by the electromagnet and delivered to Stage-02 where the pieces are further separated and singulated. This process repeats itself until the electromagnet travels to the bottom of the bin and picks all the silverware pieces left in the bin. For testing purposes, the electromagnet was lowered and lifted by hand. Each testing run consisted of separating the batch of 400 pieces into smaller batches until the bin was emptied. More than 15 runs were conducted, with the following conclusions drawn.

Pros: This method:

1. Relies on tried and tested pick and place mechanisms.
2. Is not constrained by sheet thickness as in previous method.
3. Provides additional flexibility in terms of varying the magnetic field as and when necessary.

Cons:

Despite very strong lifting capabilities of this electromagnet, due to many silverware pieces lying across various layers, as shown in Figure 2.16, the number of pieces picked by the electromagnet at each pass varied widely.

1. The average number of pieces for each batch of silverware delivered by the electromagnet to stage-02 was not enough to sustain singulation at required throughput.
2. Due to the uneven depths of the top pieces of silverware in the bin, the actuator requires sensor feedback to monitor the distance it must move at each pass for the electromagnet to stop at the point of silverware contact. The sensor would be required to reject noise and have high precision because air gaps will cause the magnetic attractive force to rapidly decrease with gap distance. A sensor of such capabilities will increase the cost of any commercial rendition of the device. Moreover, the linear actuator moving the electromagnet requires a means to enable the actuator to stop at any location in its path, as required. This will also increase the cost.
3. An alternative option would be to provide a soft cushion like support at the actuator for the electromagnet in order to absorb any collision that the electromagnet may have with silverware pieces.

Also, in order to meet the throughput, a faster actuator was required. Despite its relatively simple concept, and not many moving parts, variance in throughput was very high and hence this method was kept on the backburner to be considered later if required.

Use of Inclined Bin to Separate Silverware: A new idea was conceived that relies on use of an inclined bin along with sensing silverware weight to separate silverware pieces into smaller batches. To house silverware pieces, a bin in the shape of a box was built for this experiment, shown in Figure 2.16.

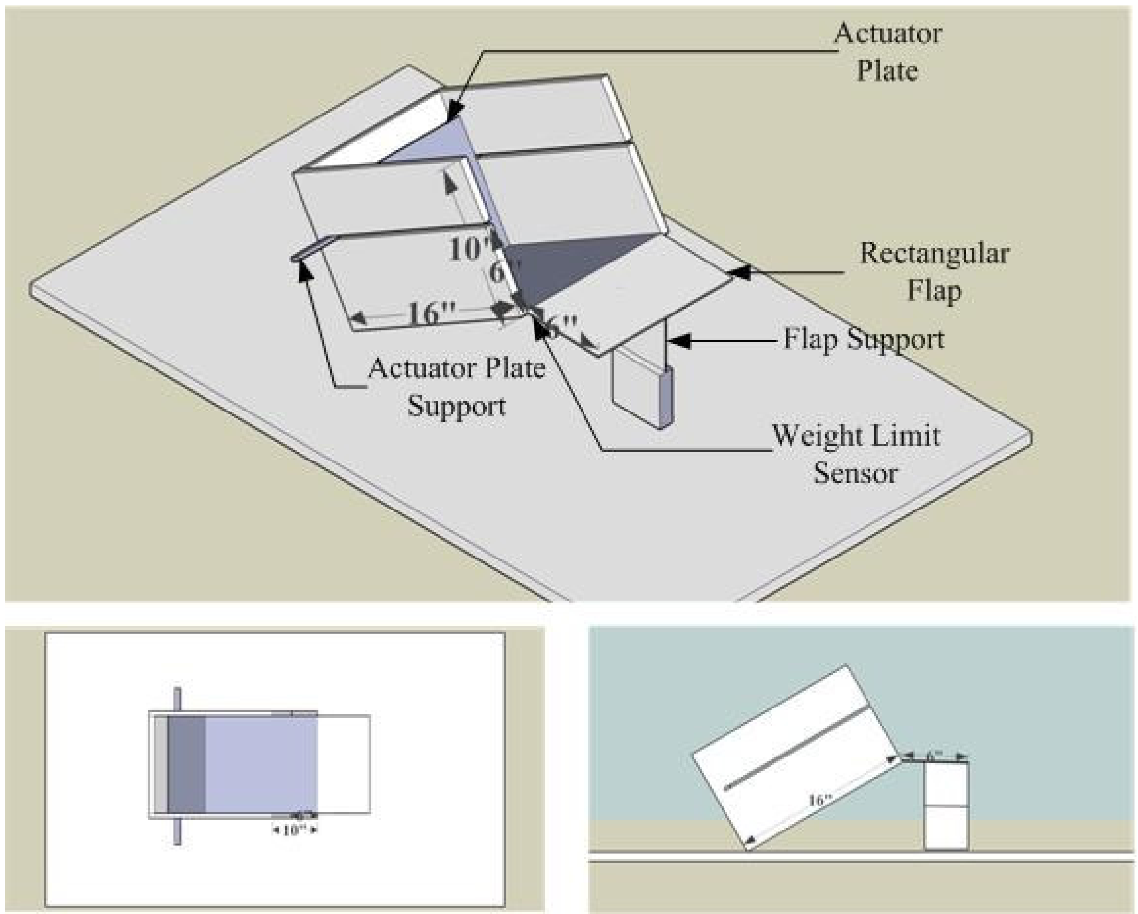


Figure 2.16: Isometric View, Top View and Side View of Inclined Bin

One side of the bin was left open for the silverware to exit the bin. At the open end of the bin, a rectangular flap was hinged to the base. Below the rectangular flap a weight limit sensor was placed. During experimentation, a thin metallic tin strip attached to underside of the flap and bin was used as a weight sensor. The flap and sensor were designed in a manner that it will hold no object beyond a pre-set weight. When there is no weight placed on the flap it would remain horizontal, and when the weight increased beyond the set limit, it would pivot about the hinge and drop the weight. A plate with support handles that functions as an actuator was fixed at the rear end of the bin. The base of the bin was reinforced with a smooth flat Masonite in order to prevent any buckling of the base due to weight of silverware.

A batch of 80 silverware pieces was input into the bin. As the actuator moved forward, the pieces were forced up along the bin surface. At the dispensing end of the bin, when the pieces approach the open end of the bin, they begin to slide onto the flap. When the combined weight of pieces that slide onto the flap exceeds the weight limit value, the silverware pieces fall off the flap. For testing purposes, the actuation for this experiment was done manually. Conclusions from testing this idea were:

Pros: This device was:

1. A simple design with not many moving parts.
2. Required only a single actuator, operating only at low speed.

Cons:

1. It was anticipated that at low actuator speeds, as the actuator plate is pushed up the incline, silverware pieces would slide up the incline. In reality, silverware pieces tended to bunch up against the actuator plate and form a heap.
2. The bin was tested at various inclination angles from the horizontal, up to 45°. On occasions as the silverware pieces approached the flap, the apparatus completely failed. Either very few pieces slid on to the flap or batches of more than 30 – 35 pieces fell in a heap on to the flap.

Due to this method showing very little promise, experiments were discontinued and the apparatus was scrapped.

2.3 New and Modified Method

Inconsistency in size of the small batches delivered onto Stage-02 prevailed across the three methods described in this chapter and the vibration method described in the previous chapter. In all the four methods, transfer of the small batches from Stage-01 onto Stage-02 was done abruptly and at equal time intervals. This proved to be the largest shortcoming among all the contributing factors for failure at required speed and efficiency. It was a case of either too many or too few silverware pieces arriving at Stage-02.

According to the earlier definitions of Stage-01 and Stage-02 in section 2.1.3,

1. **Stage-01:** To divide the batch of 400 silverware pieces into smaller batches of approximately 20 pieces each.
2. **Stage-02:** To Singulate silverware pieces from these smaller batches of 20 pieces.

Not much importance was credited to the manner of disposal of these smaller batches that arrived from Stage-01 onto Stage-02. Instead, if these smaller batches delivered from Stage-01 were slowly and consistently metered onto stage-02, then it appeared reasonable to expect that variance in the batch size will reduce and singulating efficiency will increase. A regular progression of small bundles of silverware at less than 10 pieces per bunch appeared to offer better prospects at singulation efficiency than to put 25 pieces at once onto the Stage-02 sheet. Therefore, based on these observations, the transfer of smaller batches from Stage-01 merited greater importance than before as it involved the following responsibilities:

1. Subdivide smaller batches of 20 pieces each further.
2. Regulate the size of smaller batches using feedback and actuators.

3. Meter the silverware pieces onto singulating sheet.

Therefore, in what follows, the Stage-01 will get sub-divided into two phases, assume additional responsibilities and the following definitions apply:

1. **Stage-01-A:** To divide the batch of 400 silverware pieces into smaller batches.
2. **Stage-01-B:** To subdivide, regulate and meter the smaller batches onto Stage-02.
3. **Stage-02:** To Singulate silverware pieces from these metered silverware pieces from Stage-01-B.

According to the new jargon, a solution has already been found for stage-02 using duck cloth as the sheet material and a solution is required to be found for Stage-01-A and Stage-01-B.

Among the methods discussed, use of block magnets or the inclined bin did not show enough promise for experimentations to be continued. The two methods that remained in contention were the use of an electromagnet and a vibration mechanism discussed in Chapter-01. Use of a vibration mechanism to convey silverware pieces would cost less than using linear actuators and precise sensors, and vibration appeared to offer mitigation of jamming tendencies.

Chapter-03 will present a detailed description of a new vibration-based apparatus employing electromagnets that can provide the required throughput, have high efficiency, and meet the objectives of this study. Use of sensors and their constraints, power requirements for each component in the setup and the control algorithm that functions as the brain for the setup will also be discussed in detail.

CHAPTER III

NEW AND MODIFIED METHOD

3.1 Design and Manufacturing of Stage-01-A

Dimensioned front and side views of the entire experimental test rig for our new and modified method are given in Appendix J. Stage-01-A in the proposed new method will depend on a vibration mechanism to initiate the distribution and division of 400 silverware pieces. The previous vibration setup developed (Hashimoto, 1995) is not large enough to accommodate 400 pieces of silverware. Therefore, a bin to accommodate 400 pieces of silverware was designed and constructed. Based on the previous experiments, a bin with dimensions of 24” x 18” x 8” was estimated to be sufficient for new experiments. An Isometric view, Top view and Side view of the bin is shown in Figures 3.1a and 3.1b on the following page.

The two sides and back of the bin are constructed of 0.125” thick Masonite sheet. The thickness of the base is 1”, and constructed of a 0.75” thick wooden block sandwiched between two Masonite sheets of 0.125” thickness each. The 0.125” Masonite sheet glued on top of the wooden block provides a smooth surface for silverware conveyance and also reinforces the base of the bin. The bin is much wider at end ‘A’ than at end ‘B’ as shown in Figure 3.1a. The width of end ‘B’, at 8.5”, is 0.25” wider than the length of the knife.

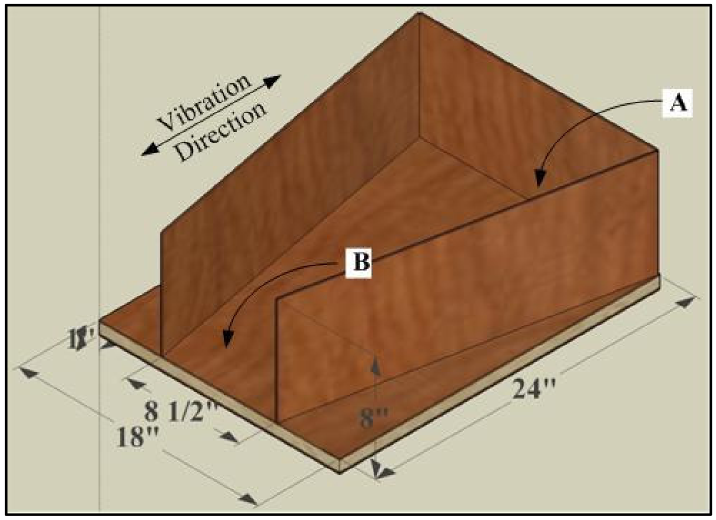


Figure 3.1a: Isometric View of Vibrating Bin

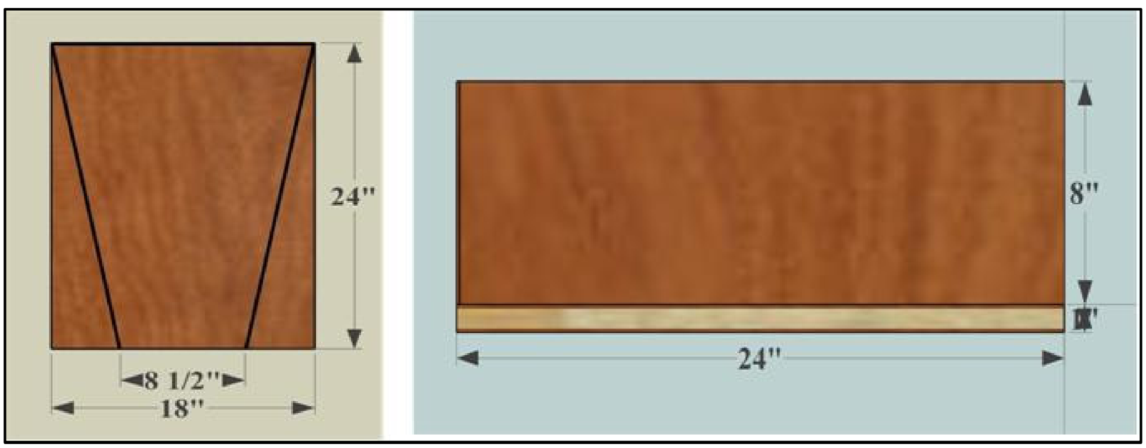


Figure 3.1b: Top View and Side View of Vibrating Bin

18 Ga. slotted angle irons were selected as mounting supports for the bin because they offer ease of use and allow flexibility in changing the inclination of the bin quickly. Each of the 4 slotted angle supports is fixed at its lower end to the support structure as shown in Figure 3.2 on the following page. At the upper end, each slotted support is connected to the base of the bin by a hinge. The rotational degree of freedom provided by hinges is useful if the inclination of bin is changed. The length of During to-and-fro motion of the bin, each of the slotted angles is subjected to a deflection that is similar to a cantilever beam subjected to a point load at its end.

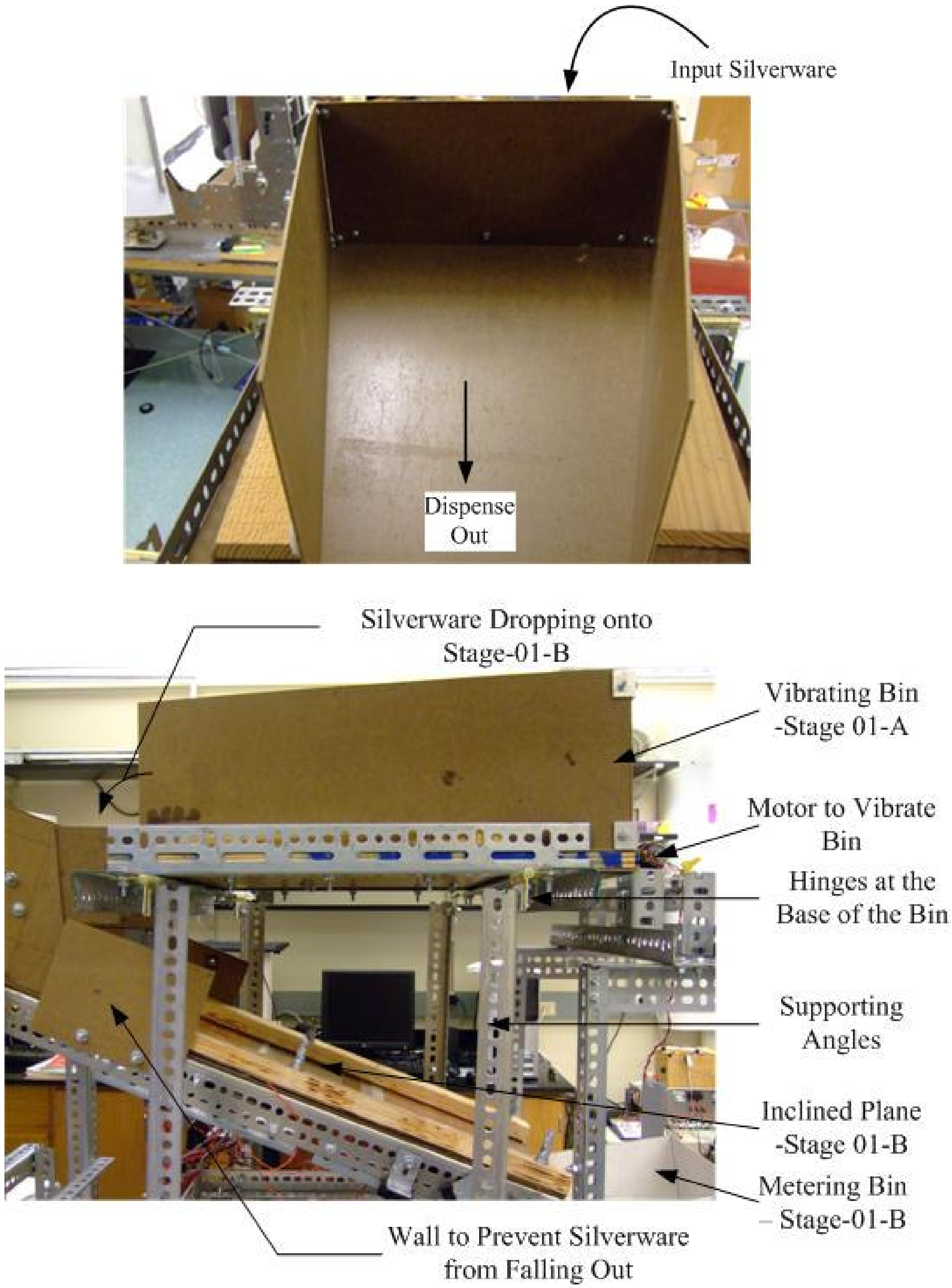


Figure 3.2: Photograph of Stage 01-A and Stage-01-B

Method of Actuation: Silverware pieces are input into the bin at the end ‘A’, and the bin is vibrated in a direction parallel to the plane of the bin bottom using an actuator. The previous method employed by Hashimoto's rig used a rotor with unbalanced mass for vibration actuation (Hashimoto, 1995). A rotor with an unbalanced mass is more suitable for operation in Hashimoto's rig due to the fact that vibration in multiple directions was required. However, in the method at hand, vibration in only one direction is required. In order to test the efficacy of vibrations induced by a rotating unbalanced mass, a few test runs were performed on Hashimoto's rig. Based on visual observations on a number of test runs, the motor-driven unbalanced mass approach did not appear to offer any additional advantages to the throughput. On the contrary, use of this method produced undesirable silverware motion, especially considering that the mass of silverware in the bin would constantly be decreasing. Experiments showed that the best dispensing rate of silverware pieces from a bin was obtained with an "in-line" vibration pattern. Reciprocating motion provided by a crank attached to the shaft of a motor can provide this vibration pattern. Moreover, in order to produce inline vibrations using rotating unbalance, synchronous rotation of two rotors with unbalanced masses in opposite directions would be required. In comparison, use of a crankshaft requires only one relatively small motor. Also, the advantage of using a motor with crankshaft to vibrate the bin is that the motor is not required to be relatively as powerful. This is because the direction of application of force is in the horizontal direction while the entire weight of the vibrating bin and the silverware pieces is in the vertical direction. If motor has enough torque to overcome the resistance offered by stiffness of mounting supports of the bin and at the same time rotate at a reasonable speed, then it should suffice the requirements of the experiment. While we could have selected motor size using mathematical modeling, we found it faster to test several motors available from storage. Two 24V Globe motors

[Models # 415A6104, 415A6178] were readily available in the lab. These models are old and presently discontinued from production. The specifications for each model obtained from vendor are listed below:

- 415A6104: Shaft diameter - 0.3175", Current – 270 mA, Resistance - 30Ω, Max. Torque – 16 oz-in, Speed @ Max. Torque – 155 rpm, Max. Speed – 190 rpm.
- 415A6178: Shaft diameter – 0.1866", Current – 650 mA, Max Torque – 36 oz-in, Speed @ Max. Torque – 90 rpm, Max. Speed – 142 rpm.

The nearest possible alternative to these models presently available at Globe Motors is the IM-13 gear motor series, model # E2135, a datasheet of which can be found in Appendix – C. The model used in this experiment is the 415A6104. The vibration stroke and frequency were determined by trial. By standard calculations this yielded the lengths of crankshaft and connecting rod shown in Figure 3.3a.

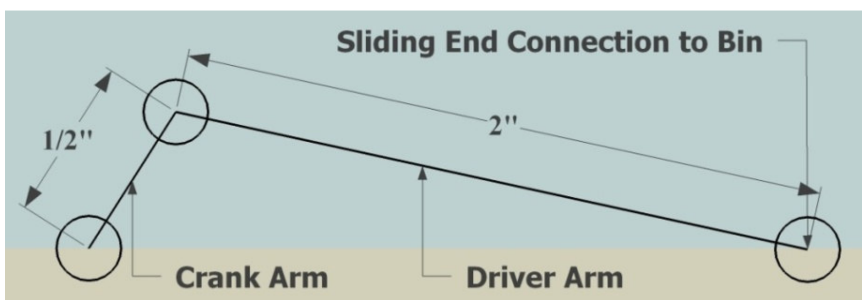
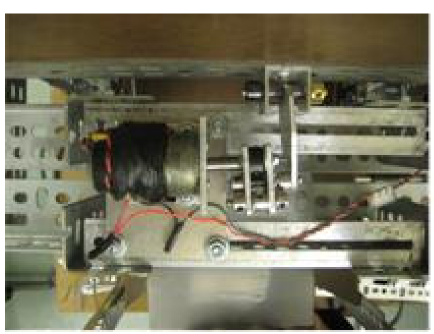


Figure 3.3a: Connecting Arm lengths for Vibrating Bin Motor



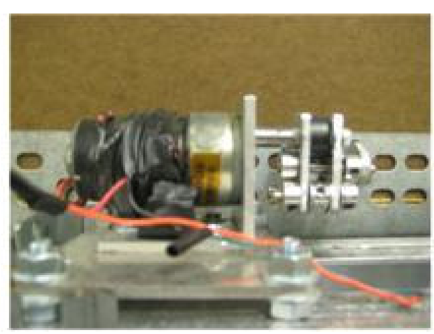


Figure 3.3b: Photographs of Motor with Crank and Connecting Arm (Slider Crank Mechanism)

From the data available on the motor and the length of the crankshaft, we determine that the frequency of vibration is 2.58 Hz and amplitude of vibration is 0.5”.

The pieces input at end ‘A’ of the bin are dispensed at end ‘B’ steadily and in small numbers during several vibration cycles. It was determined that the inclination of the bin need not be greater than 5° above or below horizontal. This is because if the inclination angle is more in either direction (upward or downward), the dispensing rate of the bin will be either too high or too low to meet the required rate of output. To find the best angle of inclination, several tests were performed, and values of these inclination angles will be presented in Chapter-04.

3.2 Design and Manufacturing of Stage-01-B

Requirements, of Stage-01-B include:

1. Receiving batches of silverware from Stage-01-A
2. Subdividing these batches into smaller size batches.
3. Dispensing these batches in a stream of silverware pieces onto Stage-02.

In order to transmit silverware pieces from the bin of Stage-01-A to Stage-02, we investigated use of a gravity fed, downward sloping inclined plane and a metering bin. This plane runs from the exit of the bin in Stage-01–A to the entrance of metering bin. Metering bin dispenses to Stage-02. Ideally, the minimum difference in height from the exit of silverware from Stage-01-A to the entry onto the inclined plane should be greater than length of a knife to prevent any jamming or blocking of silverware pieces. Also, if the height is any shorter, pieces will tend to “stand” upright, while it is desired that once the pieces exit Stage-01-A they fall flat on to the inclined plane. Once the pieces fall onto the inclined plane, they slide down under the influence of gravity. A 0.125" thick Masonite sheet of dimensions 40.5" x 11.125" was selected as the material for the inclined surface.

<u>Use of Electromagnets on the Inclined Sheet:</u> In order to further sub-divide batches of silverware pieces sliding down the incline, the electromagnet used earlier presented an option as a controlling element. In the earlier experiment with the electromagnet, the largest contribution to its non – performance was the layering of silverware. Here, silverware pieces slide down the incline largely in a single layer. And hence they are easier for the electromagnet to attract and hold. The advantage of using an electromagnet is that it does not employ a physical barrier to stop or hold silverware pieces. A barrier in the form of a physical gate to block silverware from proceeding presents a jamming possibility. An electromagnet is a non – intrusive "gate", since it can be attached underneath the Masonite incline and switched on and off as required to control the flow of silverware sliding down the incline. For testing purposes, the electromagnet was hand-held at arbitrary positions down the length of and underneath the Masonite incline. At these arbitrary positions, down the incline, the electromagnet was fixed at the width centre of the incline with its face completely in contact with Masonite as shown in Figures 3.4a, 3.4b and 3.4c. Before switching on the electromagnet and beginning to slide silverware pieces on the incline, wood sidewalls of thickness 1.25", height 2" were fixed at either side of the incline to prevent pieces exiting from side of the sheet. The width of the sheet between the walls was 8.625", or 0.5" larger than the length of the knife. The sheet was inclined at an angle of approximately 18°, which was sufficient for pieces to

overcome friction and slide down the incline. The arrangement of this entire setup is shown in Figures 3.2 and 3.4a, 3.4b, 3.4c.

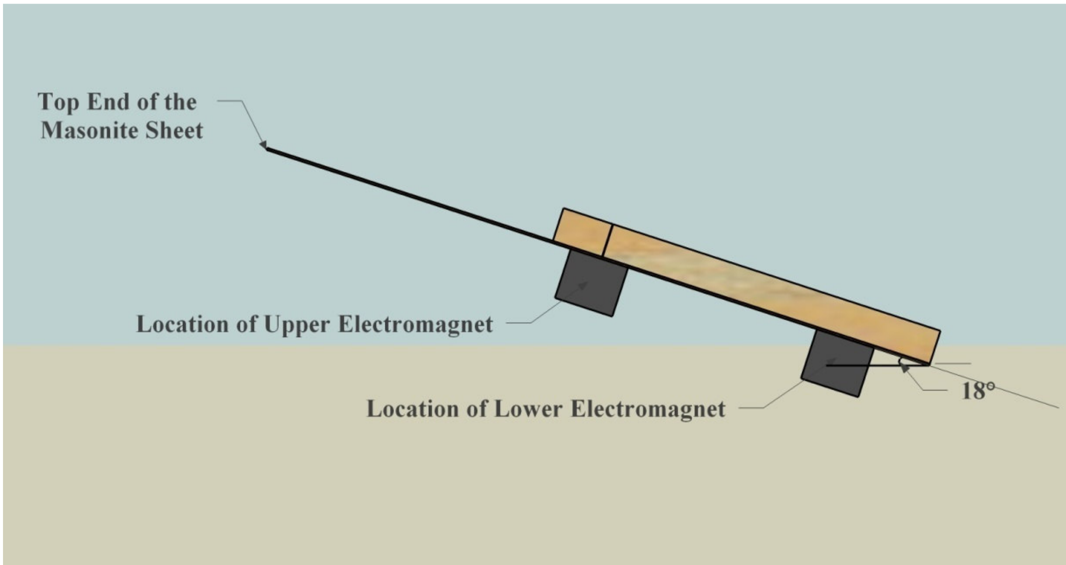


Figure 3.4a: Side View: Stage-01-A

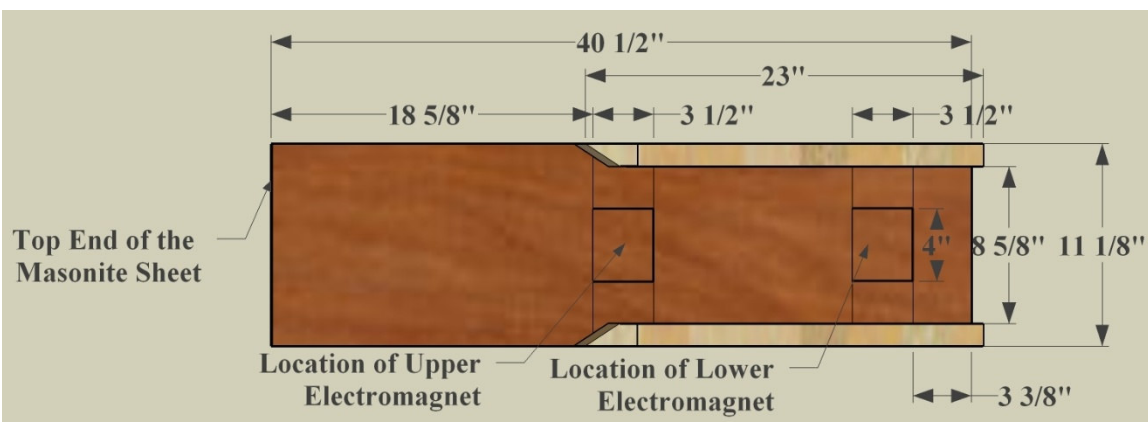


Figure 3.4b: Top View: Stage-01-A

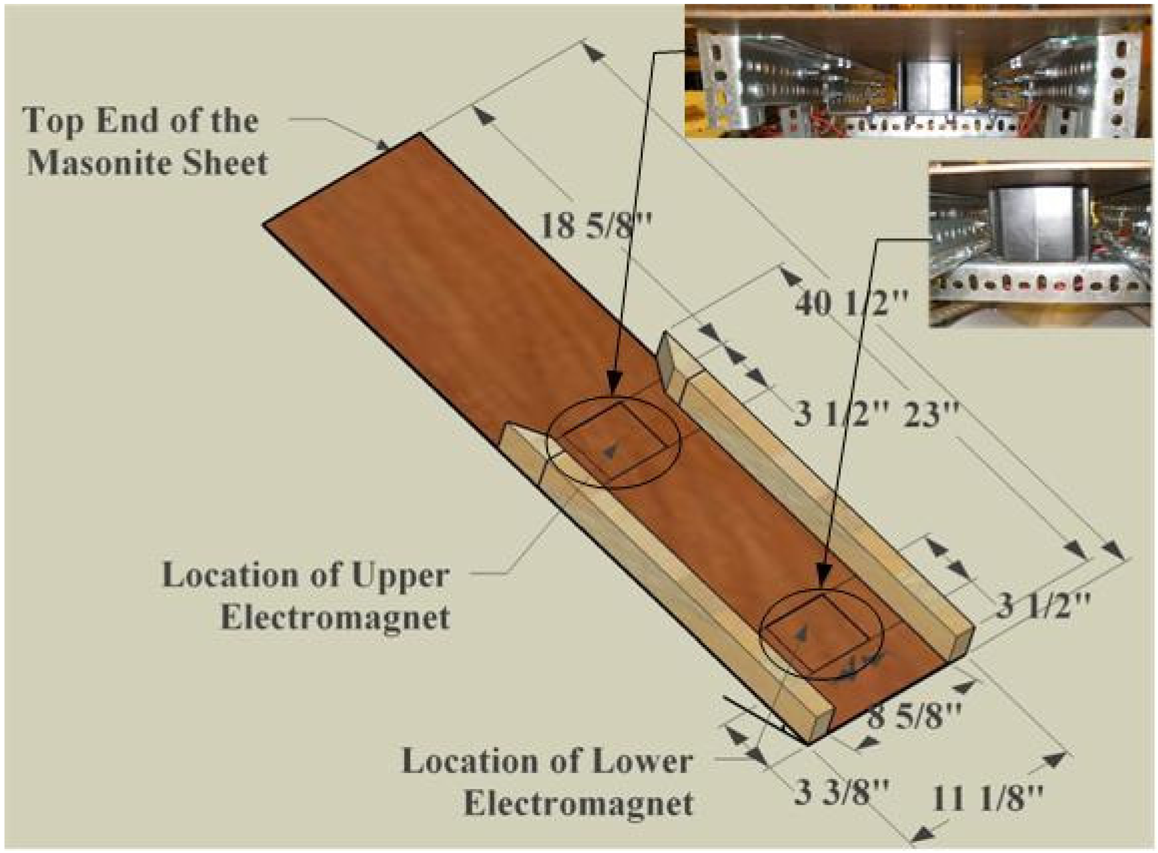


Figure 3.4c: ISO View: Stage-01-A

As the silverware pieces slide down the incline, when the electromagnet is switched on, they stop on top of the electromagnet; when is switched off, silverware pieces slide down the incline again. A number of test runs were done to check the reliability of using an electromagnet as a "gate", and results obtained were within acceptable performance limits. In order to test it further, pulsing (switching on and off) of the electromagnet was done at various frequencies to check for its ability to sub-divide a batch of silverware pieces in to multiple smaller batches. The following two observations were noted:

1. The width of the electromagnet is 4", while the width of the Masonite sheet is 8.75". The magnetic sphere of influence is only felt across the middle 4" of the

sheet, and not across the entire width of the sheet. However, pieces which are under the influence of the magnetic field tend to act as barriers or obstacles to pieces that pass on either end of the electromagnet's sphere of influence. Due to this phenomenon, most of the pieces are blocked and held back, but a few pieces still slide by.

2. The switching frequency of the electromagnet cannot be the same for batches of different sizes that slide down the incline. More pieces tend to slide down the incline for larger batch sizes for a given frequency of switching. Due to this, the batch size delivered to the Stage-02 is uncertain.

It is difficult to estimate the size of each batch that is delivered from Stage-01-A. Also, without feedback on the size of a batch, it is difficult to arrive at a specific pulsing frequency to switch the electromagnet. A constant pulsing frequency for the electromagnet is desired. In order to effectively deal with various batch sizes while maintaining a constant switching frequency, use of a second electromagnet further down the incline was investigated. It was hypothesized that a second electromagnet would function as a second gate and aid in regulating the size of these batches. Also, the distance between the locations of these two electromagnets on the inclined plane should be set greater than the length of the knife. To prevent any single piece of silverware from being attracted by both the electromagnets at the same time, ideally, the electromagnets should be placed as far apart as the geometry allows. With the dimensions given above, their locations were fixed as shown in Figures 3.4a, 3.4b, 3.4c.

Use of Solenoid and a Metering Bin: To assist with further regulating and reducing batch sizes, an inclined metering bin was placed at the downstream end of the incline. It is in the shape of a box of dimensions 14” x 9” x 7” as shown in Figure 3.5.

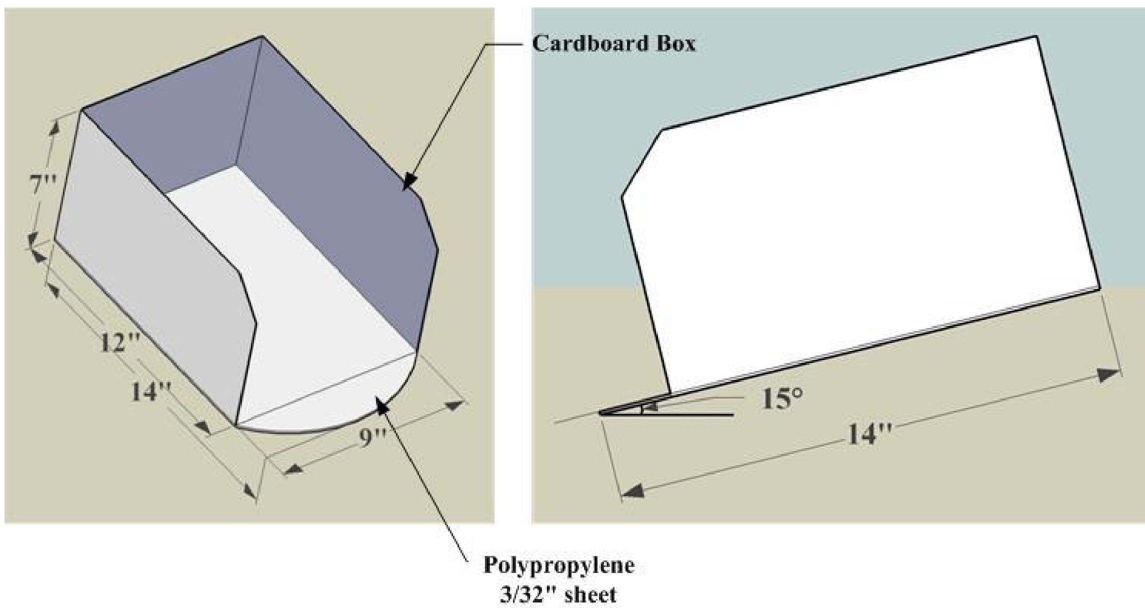


Figure 3.5: Metering Bin

The bin is made of regular cardboard with the base reinforced using a polypropylene sheet of thickness 3/32”. The bin was designed to hold up 35 pieces at a time. A solenoid [Magnetic Sensor Systems # S – 25 – 125 – 26H, Datasheet – Appendix - H] of 2.5” stroke length was placed underneath the bin, to impact the base near its center. Silverware pieces that slide past the second electromagnet reach the end of the incline and fall into this metering bin. Again, the distance from the point at which pieces exit the incline to the surface of the metering bin should be greater than the length of the knife. As soon as silverware pieces are dropped onto the metering bin, the solenoid underneath is pulsed to induce vibrations to the metering bin bottom. The pieces in the metering bin then slowly slide onto the duck cloth in Stage-02.

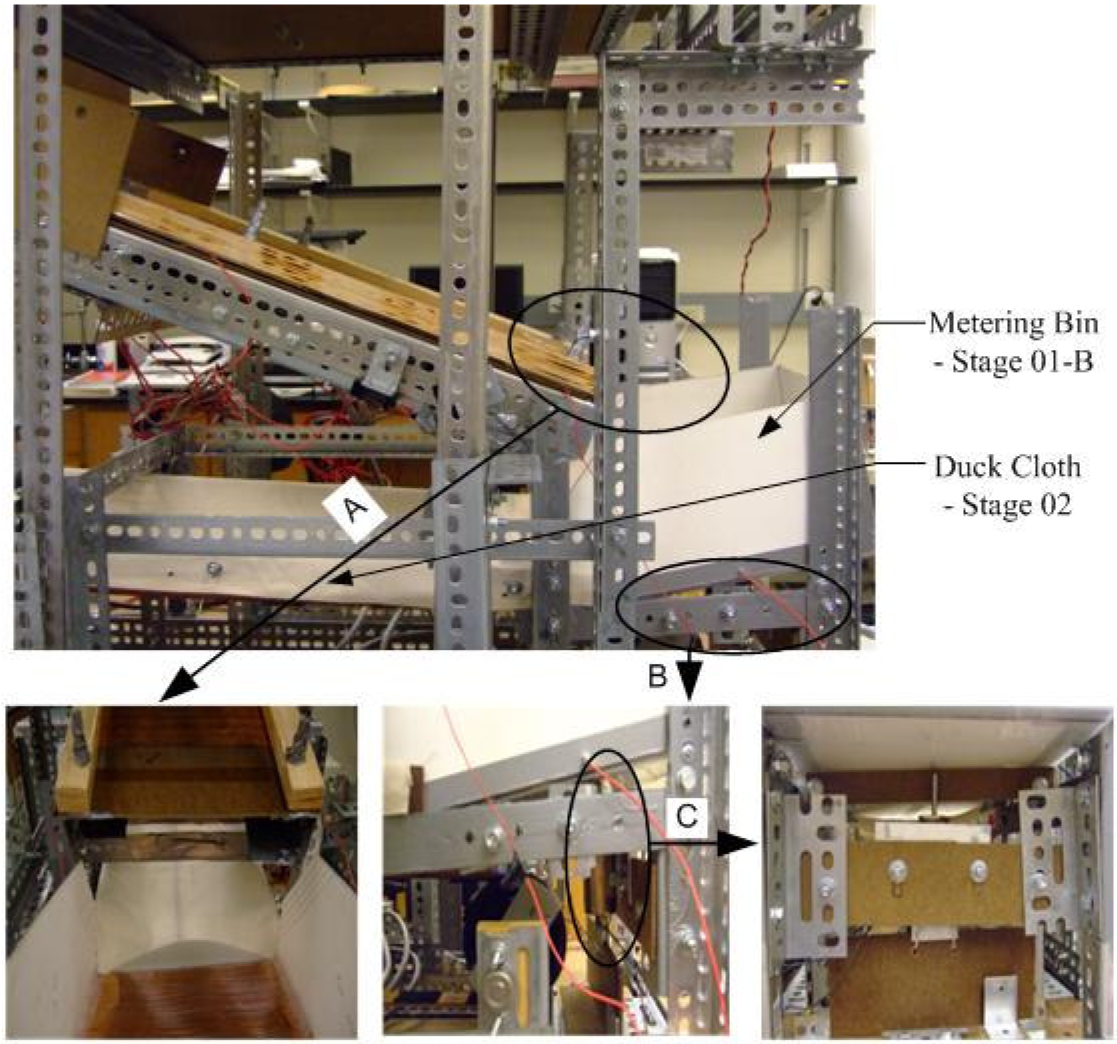


Figure 3.6: Photographs of Metering Bin and Singulation Sheet

A: Location where Silverware pieces exit Inclined Surface and Enter Metering Bin
B: Indicates the Belt Drive (Pulley) and Solenoid under Metering Bin
C: Magnified View of Solenoid Plunger under Metering Bin

The design of Stage-02 was completed in Chapter-02. The support structure for the belt drive and duck cloth was reduced in size and fixed underneath the incline. Figure 3.6 shows a side view of the experimental Setup of Stage–01-B and Stage-02. Figure 3.6 shows views looking into the metering bin and Stage-02 from the exit ends. Figure 3.7 shows photographs of Stage-02, and Figure 3.8 shows belt-drive and actuator for Stage-02.

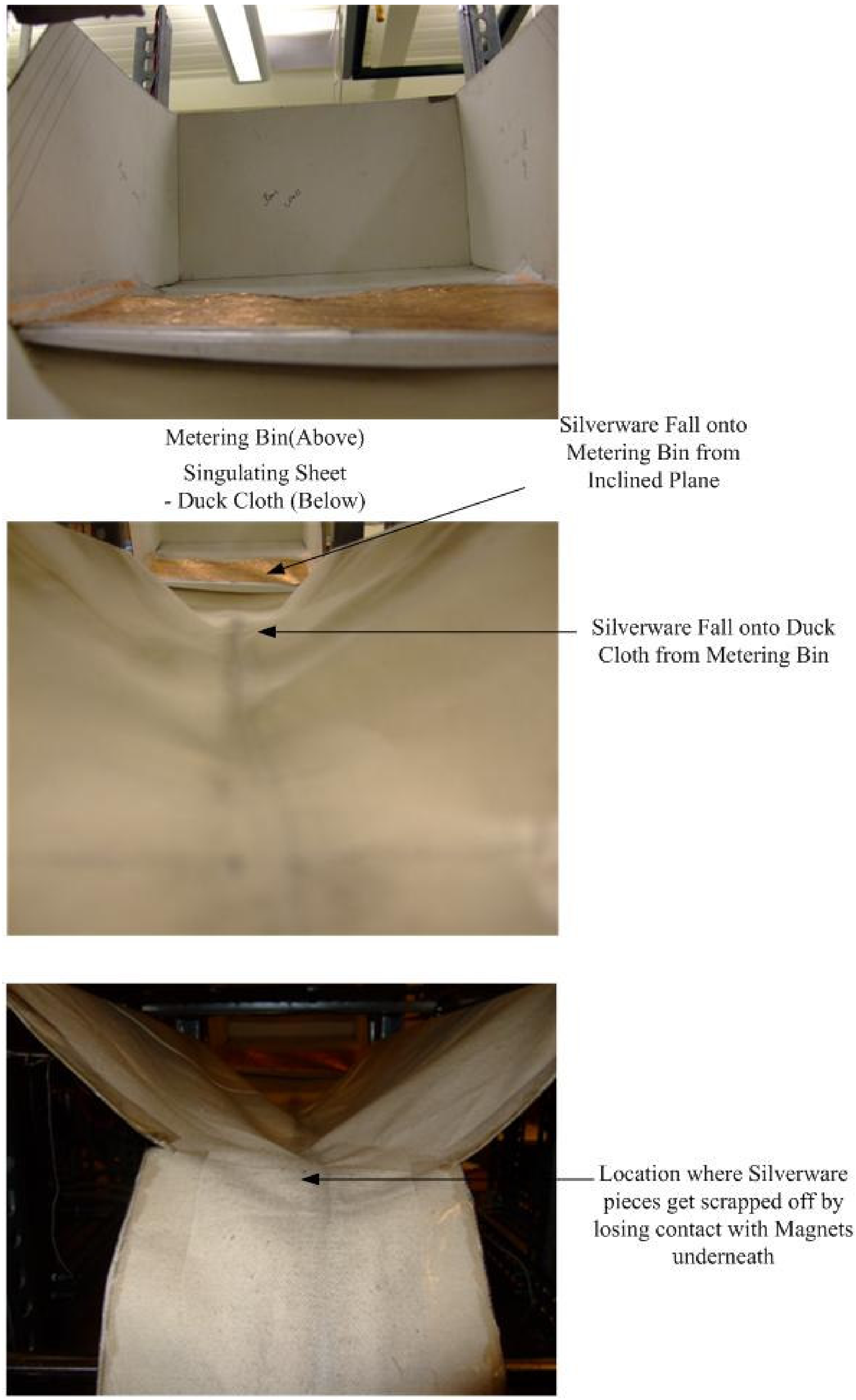


Figure 3.7: Photographs of Metering Bin and Singulation Sheet – Front View

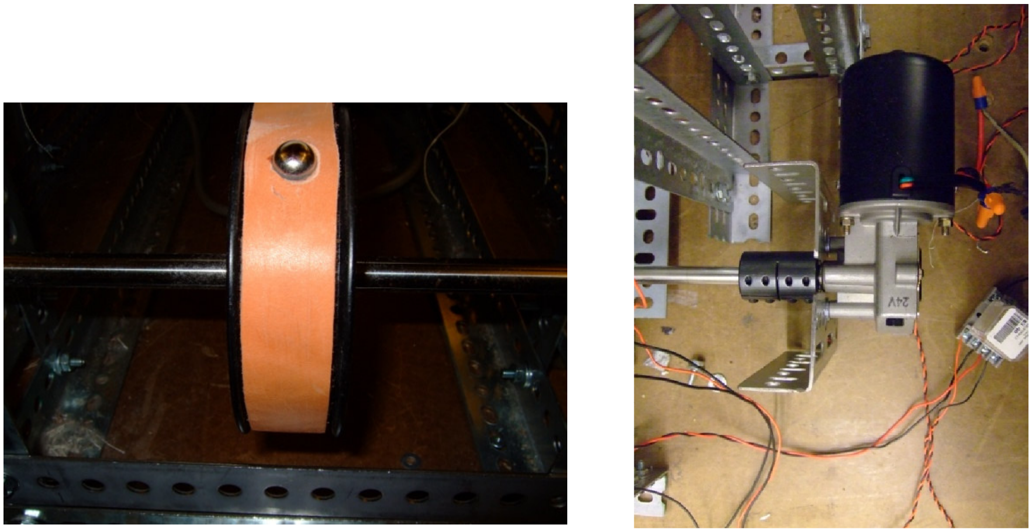


Figure 3.8: Belt Drive and 24V DC Motor - Stage 02

3.3 Investigation of Sensors

3.3.1 Existing Sensors

In the test rig, a reliable sensing method is required to provide feedback on the presence of silverware at 3 locations:

1. Location 01 – Top of the upper electromagnet
2. Location 02 – Top of the lower electromagnet
3. Location 03 – In the metering bin.

Several different sensing mechanisms were investigated to provide correct feedback for the actuators (Electromagnets and Solenoids) to perform their assigned tasks. The first sensor was a photoelectric diode pair. A photoelectric diode pair uses an emitter and a receiver to detect the presence of an object between them. A pair of photoelectric diode pairs was placed on either side of the electromagnet outside the incline sidewall, as shown in the Figure 3.9.

Holes were made in the sidewalls to allow line-of-sight from the emitter across to the receiver. Figure 3.9 shows emitters only, because the receivers are outside the opposite wall. Silverware pieces were manually fed onto the incline, and as soon as the photoelectric diodes detected an obstacle across their line of sight, they triggered a “High Signal” and the electromagnet automatically switched on stopping the flow of pieces. Due to curved shapes of spoons and soupspoons, and the narrow light beam of the photodiodes, very poor and inconsistent feedback was received. Hence use of these sensors was discarded.

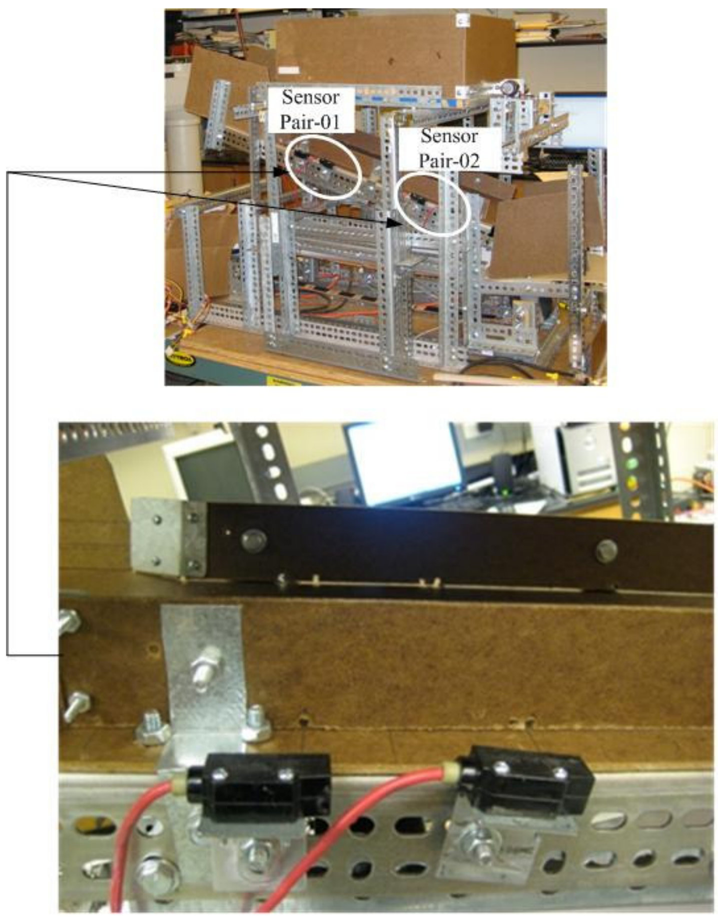


Figure 3.9 – Photoelectric Diode Sensor Pair*
***Each Sensor = One Emitter + One Receiver**

The second approach used an ultrasonic sensor. Ultrasonic sensors can be used to detect position of objects moving across them. The underlying concept is that the sensor emits an ultrasonic signal, and when the signal hits any obstacle it reflects back. The ultrasonic sensor receives the reflected signal, and provides a signal proportional to the position of the object by measuring the time difference between the two signals. We employed a Max-Botix Sonar model EZ1 ultrasonic sensor for detection of silverware. The sensor was mounted in a manner similar to the photodiode emitter. It was assumed that when a silverware piece slides into the ultrasonic sensor, field of view, the time difference between the source signal and the return signal will be sufficient to detect the presence of silverware. Due to the curved shapes of spoons and soup spoons, this sensor provided very poor feedback as well, and use of it was discarded.

A reliable sensing mechanism that could be used to detect the presence of silverware was needed. Despite searching extensively, a reliable and cost effective sensor could not be located. We decided to develop a customized sensor that could meet the needs of the experiment.

3.3.2 New Sensor Development

We proposed creating a simple pattern of unconnected conducting lines on a substrate. Initially this pattern of lines will be connected in an open circuit. When a conducting material is allowed to pass over this pattern of conducting lines, it will link the unconnected lines, thereby closing the circuit. The voltage signal from the closed circuit can be used as feedback to detect the presence of conducting material on the pattern of lines. However, commercially generating a few circuits on substrates is expensive. Hence it was decided to develop in-house low cost sensor.

Testing: For this idea to work, silverware pieces were initially tested to check for their resistance. A pair of general purpose aluminum foils was placed within 1/8" of each other and 5V DC was applied across them. Each one among four types of silverware pieces was repeatedly passed over the gap and the voltage of the circuit was measured using a multimeter. The voltages obtained were sufficient to trigger a "high". After confirmation that 5V was sufficient, in order to generate a more concrete example of the sensor, a 'comb' pattern of interlaced flat circuit wires was designed to test the concept. A 'comb' pattern has one set of parallel wires connected across a common terminal interlace with another set of parallel wires connected across a second terminal as shown in Figure 3.10a. The interlaced parallel wires do not touch each other. Therefore, when a voltage is applied across the two terminals, the circuit is open and there is no passage of current. If conductivity is established across any two adjacent conducting wires, it will close the circuit and passage of current will take place. Thus a silverware piece contacting two adjacent lines would be detected by detecting current.

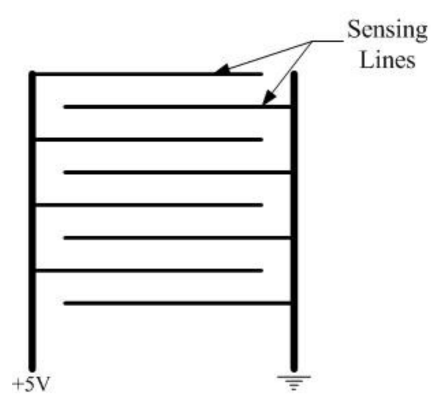


Figure 3.10a: An Example Comb Circuit

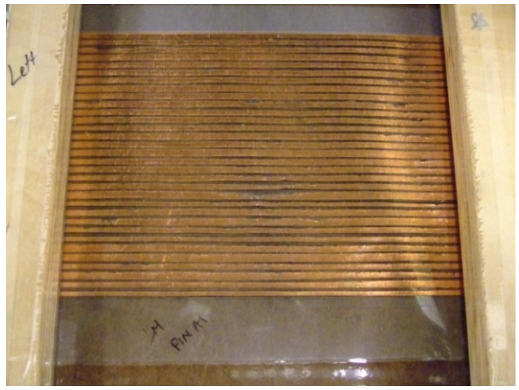


Figure 3.10b: Photograph of Comb Circuit

<u>Code to Generate Circuit Patterns:</u> A code in '.NET' was written to help generate the desired patterns of flat circuit wires and also to allow flexibility in changing other parameters, such as length of conducting wires and distance between adjacent sensing wires. The width of the circuit wires was decided by considering the silverware piece with the least cross sectional thickness. The value of this thickness is approximately 1/8". Therefore, in order for any silverware piece to rest on at least two adjacent sensing lines, the width of each sensing line and also the distance between adjacent sensing lines is required to be not greater than 1/16" for providing very reliable feedback. However, for the nature of this design, due to lack of sophisticated manufacturing techniques, the width of each sensing line and also the sensing distance between adjacent sensing lines was selected as 1/8". At a minimum, the sensor was required to provide feedback across the width of the inclined bin for the length covered by electromagnet which comes to 8.625" x 3.5". But, feedback area on the metering bin was required to cover larger area. Therefore, the size of the overall circuit was selected as 11.25" x 6", by trial and error.

The size was larger than required, but it was felt that use of excessive sensing area might be of assistance, and would not pose any disadvantages. Therefore printouts of the desired pattern were generated on a transparency, and a general purpose copper foil of width 1/8” was used as the material for the flat conducting wires. Figure 3.10b shows an example pattern of a ‘comb’ circuit. The code for generating sensing lines is given in Appendix - E.

These comb sensors were tested and gave good results in detecting silverware pieces. Accordingly, three such sensors were placed in the rig: One each above the top and bottom electromagnets on the incline, and one in the bottom of the metering bin.

3.4 Software

Proper feedback and an efficient control algorithm is necessary to integrate and co-ordinate the functions of the actuators to generate the required performance. A brief overview of the software logic will be covered here in this section, and a detailed flow chart is provided in the Appendix - I.

PIC 16F876A is a 40 pin flash microcontroller selected as the CPU for sending and receiving signals from all the actuators in the rig. A CCS compiler was used to generate the required hex files of the code written in ‘C’. The software code is provided in Appendix - F. The on-off switching of motor for the vibrating bin, the electromagnets, and the solenoid was done using DPDT relays because of high wattage requirements of these devices. Relays are electromechanical switching devices with limited switching speeds and are not as fast as transistors for switching purposes. But, due to low frequency switching requirements of this test rig, relays were selected a acceptable switching devices. The switching of these relays was done using IRF510 MOSFET transistors, which were controlled by the signals coming from the appropriate pins of the microcontroller. The motor for the Stage-02 driving the belt was not connected to the micro controller, but was manually switched on and off at the beginning and end of each experiment. The power supplies for the electromagnets and bin motor was provided using switching mode power supplies (SMPS) due to their abundant availability in the lab and also because they are very economical. A 0 – 30V variable DC power supply was used to drive the belt motor to test the belt at different speeds for singulating efficiency and throughput.

Initial Conditions: For microcontroller output signals, the initial status of the motor signal for the vibrating bin and the solenoid will be “low”, while the electromagnets will be “high”. At the beginning of the experiment, all silverware pieces are placed in the vibrating bin. The rig must be checked for the presence of silverware at any of the sensors. If any silverware piece is inadvertently at a sensor, it must be removed and put back into the bin. This is necessary because the microcontroller will check for the status of comb sensor at the top electromagnet, then checking the status of the comb sensor at the lower electromagnet followed by checking the sensor at the metering bin. Only if all the three signals are low will the experiment begin by automatically switching on the motor for the vibrating bin.

Serial Approach: Initially the software code written used a “serial” approach in which the status of the sensors is checked on a one – by – one basis. Comb sensors will trigger a “high” if a silverware piece is present on top of it, and a “low” if otherwise. In this approach, the action sequence for each actuator is defined by the status of all the sensors that are below it. This means that the motor for the vibrating bin stops dispensing pieces as soon as the sensor on the top electromagnet triggers high. The top electromagnet will not release pieces to the bottom electromagnet until the sensor at the bottom electromagnet triggers low. The sensor on the bottom electromagnet will not release pieces until the status of the sensor in the metering bin triggers low. Therefore, if the bin motor for the vibrating bin starts dispensing pieces to Stage-01-B, it can only do so after all three sensors trigger low. This is a conservative approach to avoid large batches of silverware clustering at any location in Stage-01-B and Stage-02. Although, the algorithm worked well and the actuators performed as expected with high singulating efficiencies, due to the lag in each batch delivered from Stage-01-A, the average throughput hovered around 15 pieces/min, which was unacceptably low. Accordingly, a 'parallel' approach to switching logic was developed to meet the required throughput of 30 pieces/min.

Parallel Approach: In this approach, the action sequence for each actuator is defined by a truth table for the three sensors shown in Table 3.1. Due to the presence of three sensors, there are 8 (2^3) possible configurations. A timer generated interrupt routine was implemented that checks on the status of the three sensors every 100ms. Depending on the status, for each sensor signal configuration, a well-defined action sequence was incorporated into the code. Due to this approach, the code is interrupted every 100ms. This allows the algorithm to choose the most appropriate action sequence depending on the latest sensor status. This streamlined the entire process, and the average throughput increased to acceptable levels while still being able to maintain the efficiencies obtained during the conservative serial approach.

Table 3.1: Truth Table For Sensor Configuration – Parallel Approach

Sensor Status EM-01[1]	Sensor Status EM-02[2]	Sensor Status Metering Bin	Motor for Vibrating Bin	EM-01	EM-02	Solenoid
0	0	0	1	0	0	0
0	0	1	1	0	1	1
0	1	0	1	1	0	0
0	1	1	1	1	1	1
1	0	0	0	0	0	0
1	0	1	0	0	1	1
1	1	0	0	1	0	0
1	1	1	0	1	1	1

[1]EM-01 = Upper Electromagnet; [2]EM-02 = Lower Electromagnet

As can be observed from Table 3.1, actuation for solenoid is guided by the status of the sensor in the metering bin and actuation for motor is guided by the status of the sensor on electromagnet-01.

CHAPTER IV

EXPERIMENTAL RESULTS AND DISCUSSIONS

Experiments were done on the singulation system developed in Chapter-III, and results were recorded, consisting of singulating efficiency and throughput. Singulating efficiency is defined as 100 times the ratio of the number of single pieces of silverware that the test rig produces in a single run to the total number of pieces placed in the vibrating bin at the start of the run. Throughput is defined as the number of these single pieces produced in a single test run divided by the time in minutes of the run. For each completed test run, the following six variables were recorded.

1. Number of single pieces dispensed.
2. Number of sets of 2 pieces dispensed at the same time.
3. Number of sets of 3 pieces dispensed at the same time.
4. Number of groups of larger than 3 pieces dispensed at the same time.
5. Number of silverware pieces not dispensed from the rig at the end.
6. Total time taken.

It was observed that more than 4 pieces were never dispensed in any of the test runs and therefore, 'groups' noted in Tables 4.1, 4.2, 4.3, 4.4 and 4.5, refers to a configuration when 4 pieces are dispensed at the same time.

Also, the headers for the columns titled "Numbers of Pieces in Twos", "Numbers of Pieces in Threes", and "Numbers of Pieces in Groups" in applicable tables below represent the final numerical values obtained by multiplying the actual experimental numbers with their corresponding multipliers. For example, in the Table 4.1, on row 1, columns 2, 3 and 4, 24 represents *twelve sets* of 2 pieces, 6 represents *two sets* of 3 pieces and 4 represents *one set* of 4 pieces respectively.

Due to the presence of six variables, for purposes of clarity and ease of understanding, the results obtained have been sub-divided into two sections. In Section 4.1, the test results are reported for singulating efficiency. In section 4.2, test results are reported for throughput. A listing of the testing conditions for each stage is given below:

<u>Stage-01:</u>

1. The vibrating bin was tested under two configurations. In the first configuration, the bin was inclined upward, hereafter referred to as UIC (Upward Incline Configuration), at an angle of 0.93° (≈ 1°) with respect to horizontal. This angle represents the limiting angle of upward inclination for the bin. Whenever the upward inclination was higher, the throughput of the vibrating bin became very low, reducing the overall throughput of the system. Moreover, higher numbers of pieces were left in the bin and never dispensed, reducing overall efficiency. In the second configuration, the bin was inclined downward, hereafter referred to as DIC (Downward Incline Configuration), at an angle of 1.85° (≈ 2°) with respect to horizontal. This angle represents the limiting angle for the downward inclination for the bin. When the downward inclination was greater, the bin delivered more

pieces than the lower stages could handle, resulting in jamming of pieces at Stages-02 and 03.

2. The vibration frequency of the bin and stroke remained constant at 2.58 Hz and 0.5 in respectively, with the motor receiving a constant voltage of 24V DC. The motor was always run at a constant voltage of 24V DC.

<u>Stage-02:</u>

1. The inclination of the Masonite sheet for was set at an angle of approximately 20.7° below horizontal. This is the smallest angle at which silverware pieces overcame friction offered by the copper wires of the sensor and slid down the incline.
2. Both the DC electromagnets were operated at 5V DC input, which generated sufficient magnetic field to meet the requirements of this experiment.

<u>Stage-03:</u>

1. The belt motor voltage inputs were of 18V, 21V, 24V and 27V to test for the best singulating performance. The line speed of the belt magnets at these voltages were 52 magnets/min, 59 magnets/min, 67 magnets/min and 76 magnets/min respectively. At UIC, 18V, 21V and 24V were applied while at DIC, 24V and 27V were applied. The hemispherical magnets on the belt were equally spaced 10 in apart.

These choices were made because at UIC, pieces of silverware were dispensed slowly, such that lower belt speeds were required to find the best combination of dispensing speed and belt speed at which the required throughput of 30 pieces/min could be met. At the other extreme, dispensing is faster at DIC, such higher belt speeds were required to find the maximum throughput the system could deliver.

4.1 Efficiency Results at Various Belt Speeds

Case 01: Belt Speed @ 52 magnets/min – UIC

Table 4.1 – Distribution of Silverware for Belt Speed @ 52 magnets/min – UIC

S.N	*Total Numbers of Silverware Pieces*	*Numbers of Pieces in Twos*	*Numbers of Pieces in Threes*	*Numbers of Pieces in Groups*	*Numbers of Pieces Left Over*	*Numbers of Singulated Pieces*
1	400	24	6	4	7	359
2	400	28	6	4	5	357
3	400	16	3	4	9	368
Avg.	400	22.67	5	4	7	361.33

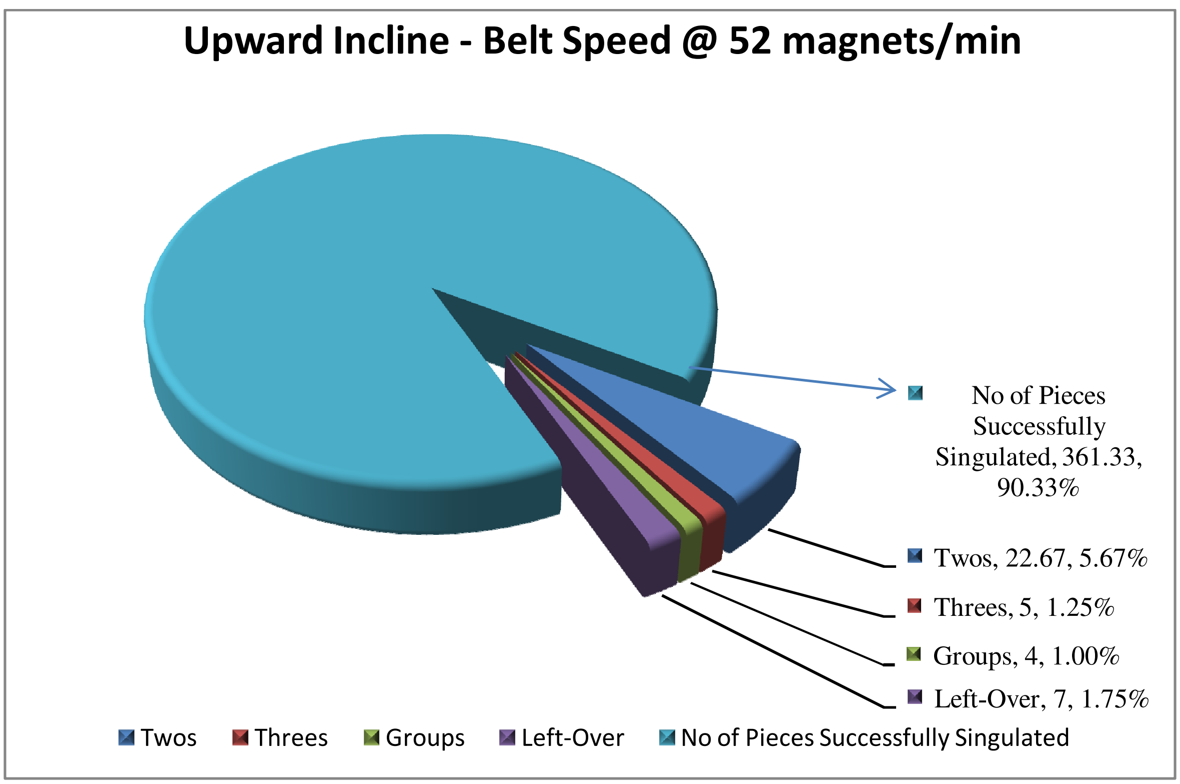


Figure 4.1: Average Distribution of Pieces for Belt Speed @ 52 magnets/min – UIC

As shown in Table 4.1, test runs were made at these conditions and the average singulating efficiency obtained was 90.33% as seen in Figure 4.1.

Case 02: Belt Speed @ 59 magnets/min – UIC

Table 4.2 – Distribution of Silverware for Belt Speed @ 59 magnets/min – UIC

S.N	*Total Numbers of Silverware Pieces*	*Numbers of Pieces in Twos*	*Numbers of Pieces in Threes*	*Numbers of Pieces in Groups*	*Numbers of Pieces Left Over*	*Numbers of Singulated Pieces*
1	400	32	0	0	7	361
2	400	36	0	0	6	358
3	400	32	0	0	5	363
Avg.	400	33.33	0	0	6	360.67

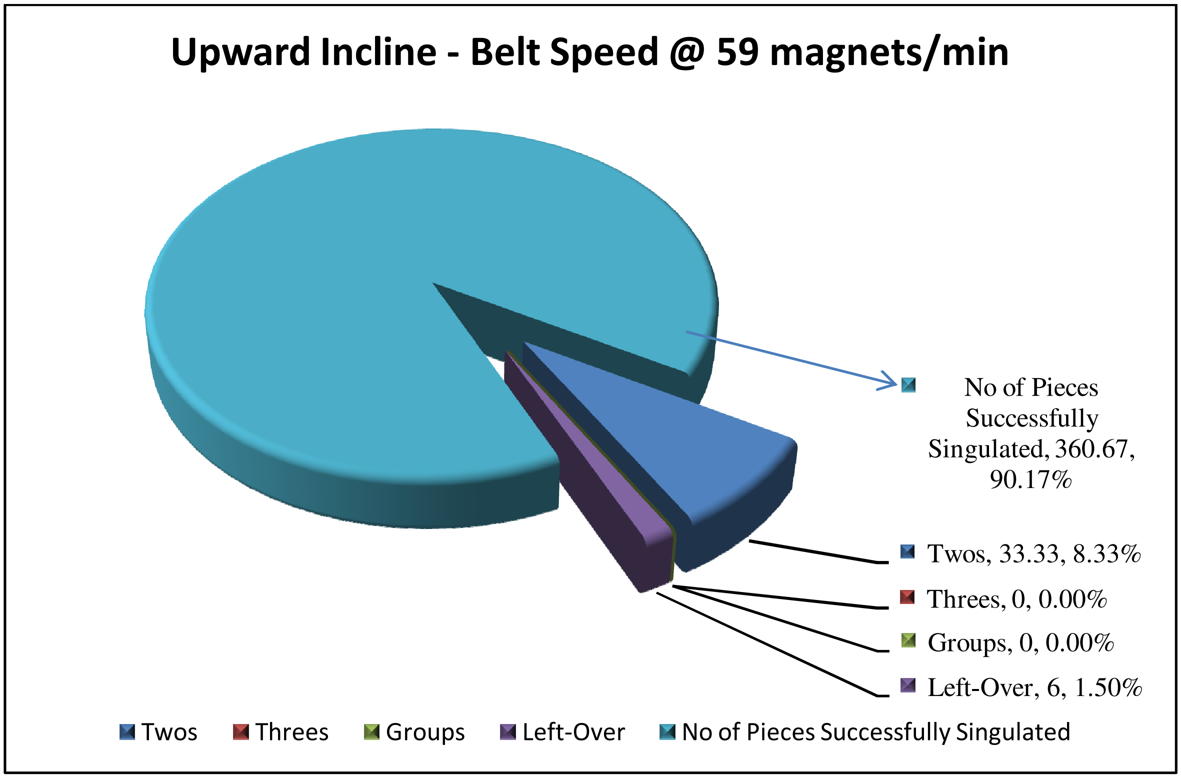


Figure 4.2: Average Distribution of Pieces for Belt Speed @ 59 magnets/min – UIC

Table 4.2 shows three test runs at these conditions and the average singulating efficiency obtained was 90.17% as shown in Figure 4.2.

Case 03: Belt Speed @ 67 magnets/min – UIC

Table 4.3 – Distribution of Silverware for Belt Speed @ 67 magnets/min – UIC

S.N	*Total Numbers of Silverware Pieces*	*Numbers of Pieces in Twos*	*Numbers of Pieces in Threes*	*Numbers of Pieces in Groups*	*Numbers of Pieces Left Over*	*Numbers of Singulated Pieces*
1	400	8	0	0	3	389
2	400	8	0	0	4	388
3	400	24	0	0	4	372
4	400	28	3	0	3	366
5	400	18	0	0	9	373
Average	400	17.2	0.6	0	4.6	377.6

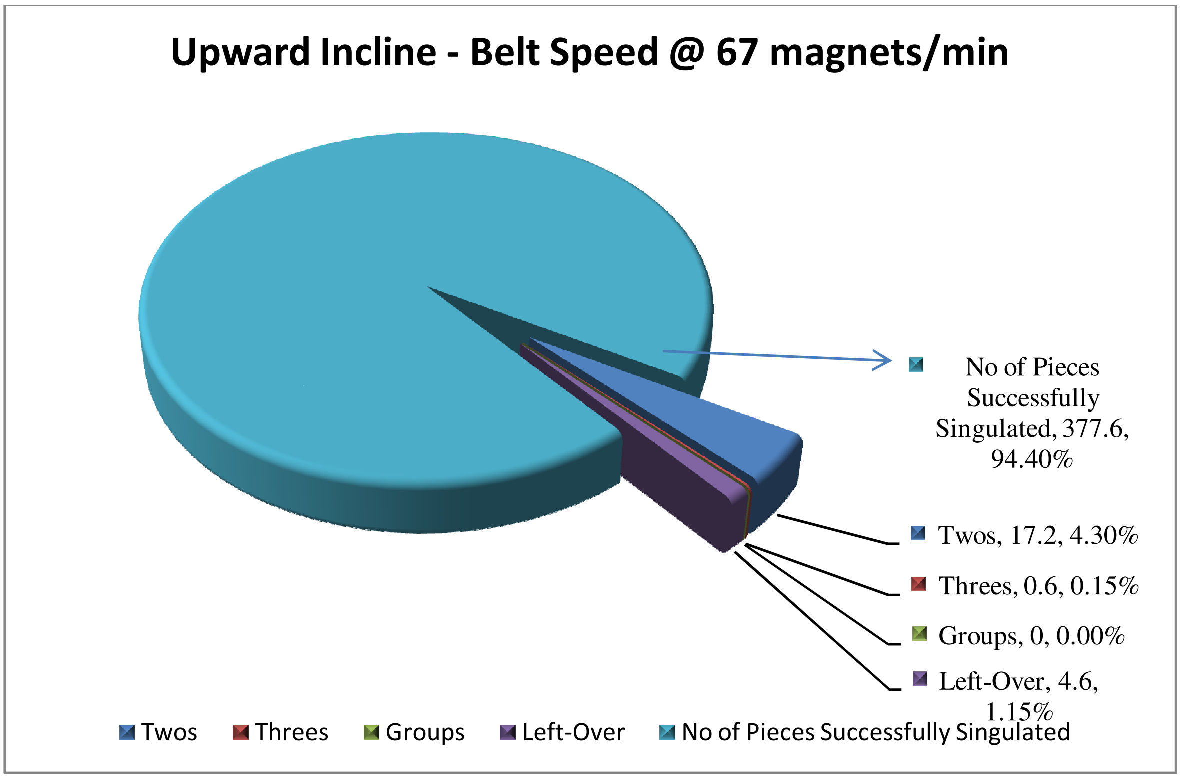


Figure 4.3: Average Distribution of Pieces for Belt Speed @ 67 magnets/min – UIC

Five test runs were made at these conditions and the average singulating efficiency obtained was 94.4%, as shown in Figure 4.3.

<u>Case 04:</u> Belt Speed @ 67 magnets/min – DIC

Table 4.4 – Distribution of Silverware for Belt Speed @ 67 magnets/min – DIC

S.N	*Total Numbers of Silverware Pieces*	*Numbers of Pieces in Twos*	*Numbers of Pieces in Threes*	*Numbers of Pieces in Groups*	*Numbers of Pieces Left Over*	*Numbers of Singulated Pieces*
1	400	24	0	0	1	375
2	400	18	0	0	0	382
3	400	20	0	0	1	379
4	400	4	0	0	0	396
5	400	18	3	0	1	378
6	400	28	3	0	0	369
Average	400	18.67	1	0	0.5	379.83

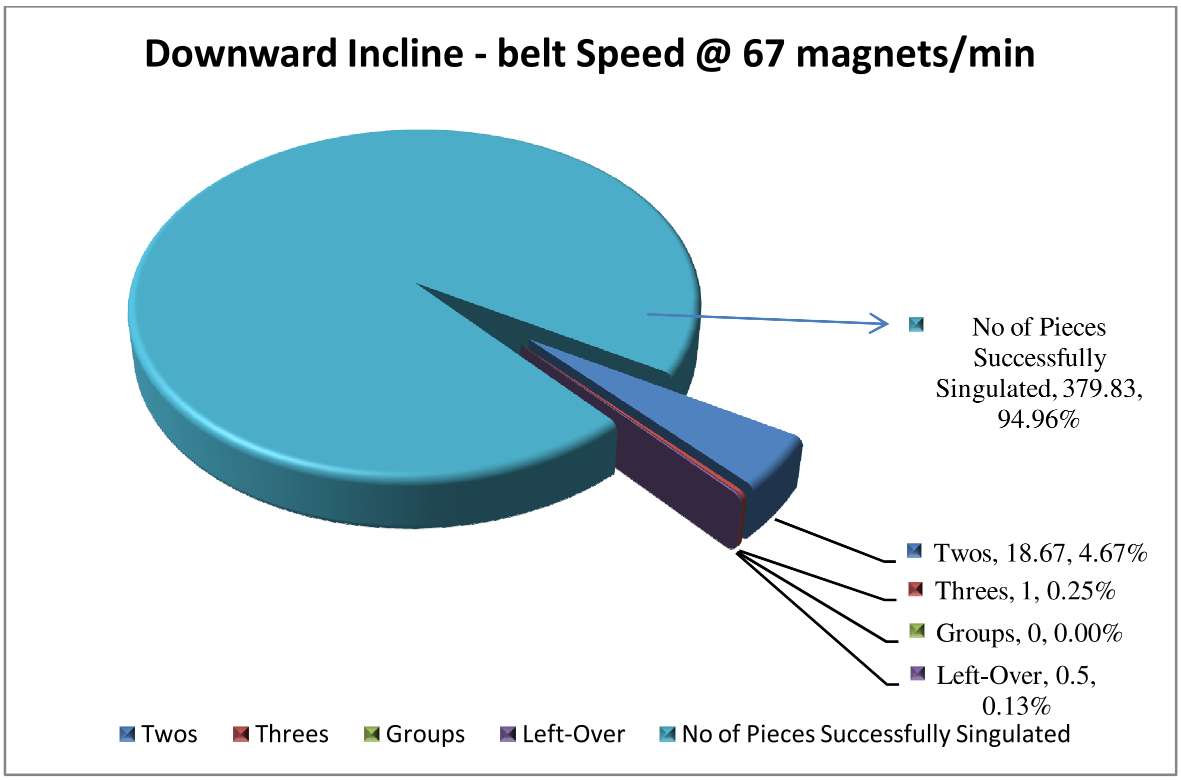


Figure 4.4: Average Distribution of Pieces for Belt Speed @ 67 magnets/min – DIC

Six test runs were made at these conditions and the average singulating efficiency obtained was 94.96%, as shown in Figure 4.4.

Case 05: Belt Speed @ 76 magnets/min – DIC

Table 4.5 – Distribution of Silverware for Belt Speed @ 76 magnets/min – DIC

S.N	*Total Numbers of Silverware Pieces*	*Numbers of Pieces in Twos*	*Numbers of Pieces in Threes*	*Numbers of Pieces in Groups*	*Numbers of Pieces Left Over*	*Numbers of Singulated Pieces*
1	400	12	3	0	1	384
2	400	12	0	0	1	387
3	400	24	3	0	0	373
4	400	12	3	0	1	384
5	400	18	0	0	0	382
6	400	18	3	0	2	377
7	400	32	0	4	0	364
Average	400	18.29	1.71	0.57	0.71	378.72

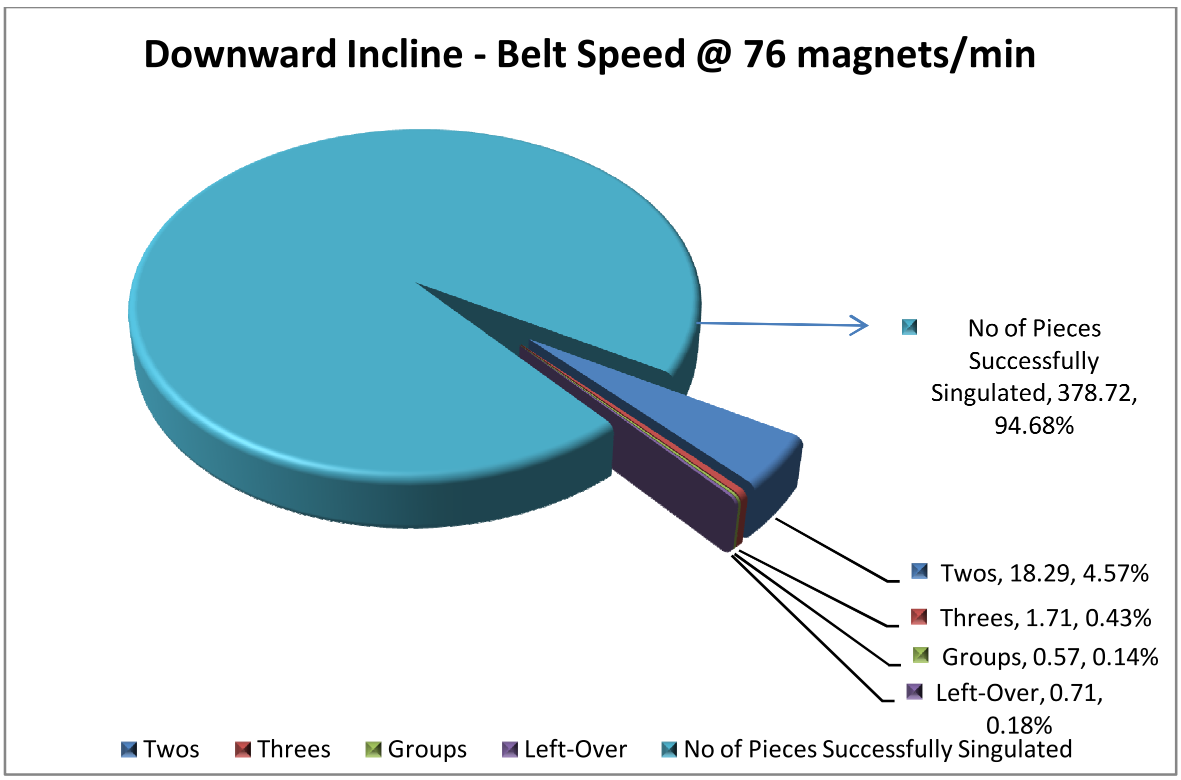


Figure 4.5: Average Distribution of Pieces for Belt Speed @ 76 magnets/min – DIC

Five test runs were made at these conditions and the average singulating efficiency obtained was 94.68% as shown in Figure 4.5.

For all the 5 cases discussed above, the singulating efficiency for individual test runs ranged from a low value of 89.25% to a high of 99%. The average efficiencies varied from 90.33% to 94.96%. The overall average efficiency for all the test runs at all configurations is ≈ 92.9%.

4.2 Throughput Results at Various Belt Speeds

<u>Cases 01, 02, 03, 04, 05:</u> Figure 4.6 shows the throughput performance of the test rig for all test runs.

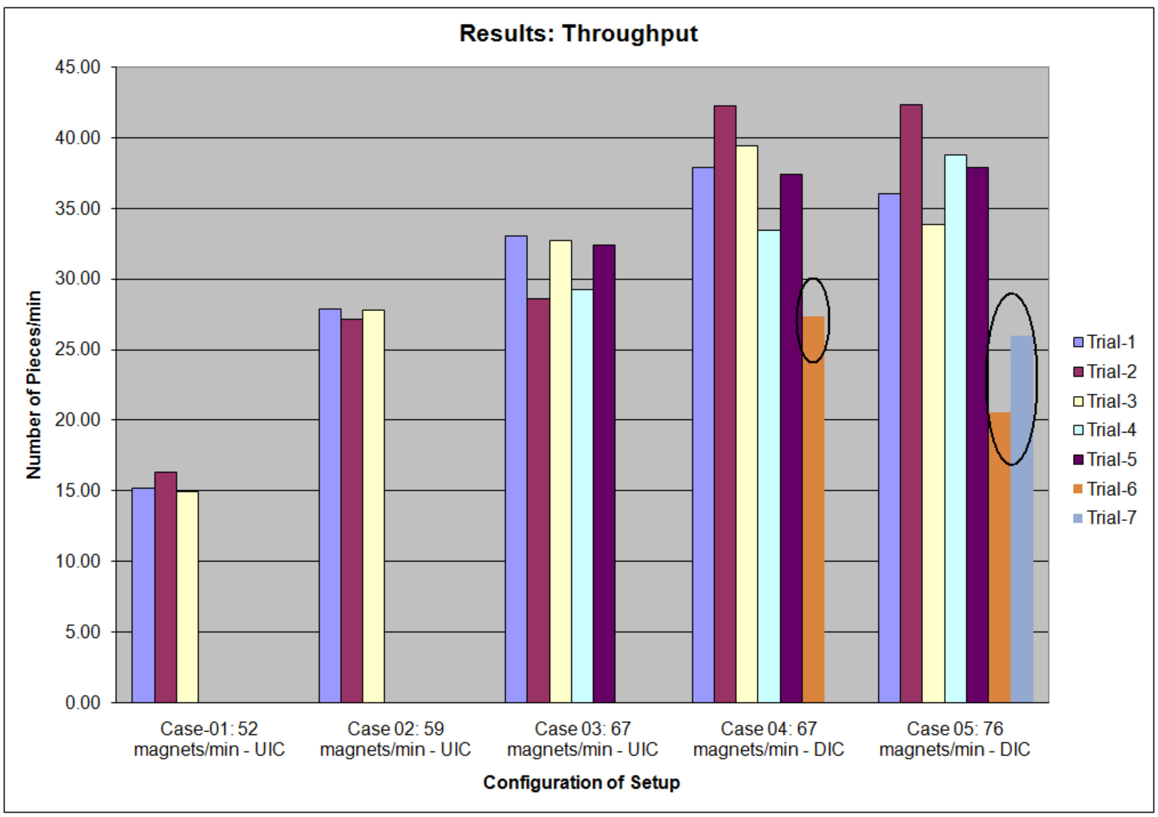


Figure 4.6: Singulation Throughput for All Test Runs

The scatter in the data for each series in Figure 4.6 arises from the randomness of the orientations and arrangement of silverware in the vibrating bin at beginning of each test run. However the increasing trend in throughput of the rig can be observed as the belt speed increases from 52 magnets/min to 76 magnets/min. The individual throughput performances are shown indicated in Tables 4.6 and 4.7.

Table 4.6: Singulating Throughput for Belt Speeds @ 52 magnets/min and 59 magnets/min - UIC

S.N	Number of Singulated Pieces	Total Time Taken (Sec)	Number of Singulated Pieces/Min
1[1]	**359**	**1418**	**15.19**
2[1]	**357**	**1311**	**16.34**
3[1]	**368**	**1478**	**14.94**
Average	**361.33**	**1402.33**	**15.49**
1[2]	**361**	**777**	**27.88**
2[2]	**358**	**791**	**27.16**
3[2]	**363**	**783**	**27.82**
Average	**360.67**	**783.67**	**27.62**

[1] = Test Runs for Belt Speed @ 52 magnets/min – UIC;
[2] = Test Runs for Belt Speed @ 59 magnets/min - UIC

Table 4.7: Singulating Throughput for Belt Speeds @ 67 magnets/min – UIC; 67 magnets/min – DIC and 76 magnets/min - DIC

S.N	Number of Singulated Pieces	Total Time Taken (Sec)	Number of Singulated Pieces/Min
1[1]	**389**	**707**	**33.01**
2[1]	**388**	**815**	**28.56**
3[1]	**372**	**682**	**32.73**
4[1]	**366**	**751**	**29.24**
5[1]	**373**	**690**	**32.43**
Average	**377.6**	**729**	**31.07**
1[2]	**375**	**594**	**37.88**
2[2]	**382**	**542**	**42.29**
3[2]	**379**	**577**	**39.41**
4[2]	**396**	**711**	**33.42**
5[2]	**378**	**606**	**37.43**
6[2]	**369**	**811**	**27.30**
Average	**379.83**	**640.17**	**35.60**

Table 4.7 Continued: Singulating Throughput for Belt Speeds @ 67 magnets/min – UIC; 67 magnets/min – DIC and 76 magnets/min - DIC

S.N	Number of Singulated Pieces	Total Time Taken (Sec)	Number of Singulated Pieces/Min
1[3]	**384**	**640**	**36.00**
2[3]	**387**	**548**	**42.37**
3[3]	**373**	**661**	**33.86**
4[3]	**384**	**594**	**38.79**
5[3]	**382**	**605**	**37.88**
6[3]	**377**	**1104**	**20.49**
7[3]	**364**	**842**	**25.94**
Average	**378.72**	**713.43**	**31.85**

[1] = Test Runs for Belt Speed @ 67 magnets/min – UIC;
[2] = Test Runs for Belt Speed @ 67 magnets/min – DIC;
[3] = Test Runs for Belt Speed @ 76 magnets/min – DIC

Table 4.6 shows the throughput of the test rig obtained in each test run for Cases 01 and 02. The average singulation throughput achieved for belt speeds at 52 magnets/min and 59 magnets/min is 15.49 pieces/min and 27.62 pieces/min respectively. The performance at 52 magnets/min fell short of the desired throughput and is not considered acceptable while the performance at 59 magnets/min was much closer to the desired target.

Table 4.7 displays performances of the rig for belt speeds at 67 magnets/min – UIC, 67 magnets/min – DIC and 76 magnets/min – DIC. The average singulation throughput achieved for belt speeds of 67 magnets/min UIC, 67 magnets/min DIC and 76 magnets/min DIC is 31.194 pieces/min, 35.6 pieces/min and 31.85 pieces/min respectively. The performances at all the three configurations achieved the desired throughput. The failed test runs for belt speed of 67 magnets/min-DIC performed at 27.3 pieces/min, and at 76 magnets-DIC performed at 20.49 pieces/min and 25.94 pieces/min, shown by ellipses in Figure 4.6. The reasons for failure will be addressed in Chapter-05.

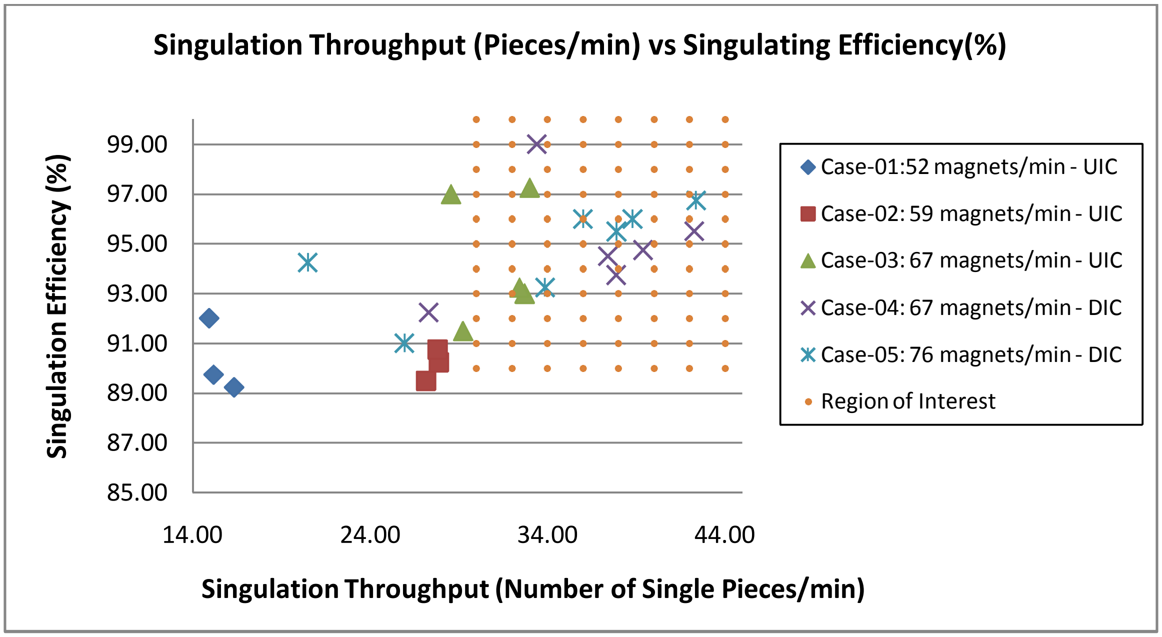


Figure 4.7: Singulation Throughput vs Singulating Efficiency for All Test Runs

By plotting all the data from the experimental test runs in a scatter diagram of singulation efficiency vs. throughput, shown in Figure 4.7, we observe a general upward trend of singulation efficiency with singulation throughput. The matrix of dots shown in Figure 4.7 shows the region of acceptable targeted performance for our singulation system, namely singulation efficiency of 90% or larger, and singulation throughput of 30 pieces/min or larger. We observe that more than half of the test runs produced results lying within this region. Overall, the singulation system designed and developed in this research displayed good singulating efficiency and met the required throughput. The best conditions for operation, considering highest throughput and highest efficiency, were at downward inclination of the incline and a belt speed of 67 magnets/min DIC, which yielded 94.96% efficiency and 35.6 pieces/min This singulation system can be improved with a few design modifications that will also be addressed in Chapter-05.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The focus of this research has been on design, development, testing, and evaluation of a silverware singulation mechanism. Results obtained in Chapter 04 demonstrate successful development of a capable singulating apparatus that can retrieve single silverware pieces at reasonable throughput and high efficiency. The average efficiency and singulating speed of the present apparatus is shown in Table 5.1.

Table 5.1 Efficiency and Singulating Speed of Present Setup

Trials	Average Singulating Efficiency (%)	Average Singulating Speed (Number of single pieces/min)
Overall Trials[1]	92.9	28.41
At Best Configuration[2]	94.96	35.6

[1]Overall Trials = 24 (includes all test runs)
[2]Best Configuration: @ Belt speed 67 magnets/min DIC

In Table 5.1, overall trials include results obtained from both successful and failed test runs. Trials "at best configuration" were obtained by including test runs for belt speed @ 67 magnets/min - UIC. These results represent an improvement in efficiency of more than 53% over previous singulation work (Hashimoto, 1995); Average throughput of all completed test runs was 28.41 pieces/min. However, the average throughput at the best configuration was 35.6 pieces/min, representing 118% of targeted results. Use of better manufacturing methods and improving precision can further aid in increasing speed and efficiency. The total cost of materials and supplies in the rig, excluding the power supplies and silverware pieces, was approximately $750. With a few design modifications and mass manufacturing methods, the cost of producing machine appears quite reasonable.

Shortcomings: Despite good improvement shown in average efficiency and singulating speeds over previous, there were occasional failures in meeting the desired throughput. These were due to:

1. Non uniform dispensing from Stage-01.
2. Friction from by sensors in Stage-02.
3. Excessive pieces in the metering bin that overwhelmed the solenoid, causing the metering mechanism to underperform.

Several recommendations are proposed in Section 5.3 to address these problems.

5.2 Contributions

This research has contributed the following:

- Development of a mechanism to distribute and divide a large batch of silverware pieces into smaller batches of silverware.

- Design and development of a controlling method to address the random sizes of small batches, subdivide them further and meter these subdivided batches onto the next stage.
- Design and development of an effective, novel and economical sensing method to detect the presence of silverware at multiple locations in the test rig.
- Effective use of sensors to provide reasonably accurate and timely feedback to actuators.
- Effective use of electromagnets as controlling elements in reducing the sizes of the batches to more manageable sizes as silverware pieces slide above these electromagnets.
- Effective use of a solenoid as a controlling element to meter silverware pieces.
- Design and development of a mechanism to pick single pieces of silverware from a stream of silverware.
- Effective use of hemispherical magnets in picking single pieces of silverware.
- Effective use of available space for the rig by locating the 3 stages on top of one another in a layer like arrangement. A more compact rig was realized as a result of this arrangement.

The sensing mechanism developed to detect the presence of silverware in this method has a design that is very flexible, allowing it to be changed according to the requirements of the problem, and can be used in many other applications to detect the presence of metal. Additionally, the flexibility in its design allows it be used for a wide range of sizes of metal other than silverware pieces.

5.3 Recommendations

Improvements to Stage-01-A: Stage-01-A is the weakest performing area in the rig. Though the vibrating bin distributes and divides the batch of 400 silverware pieces, there still exists discontinuity in delivering of silverware pieces to Stage-01-B. Possible solutions to prevent this are:

- Employing a motor with higher torque and speed capabilities that can allow a greater range of frequency of vibration applied to vibrating bin.
- Change in length of linkage arm from the crank to the bin to increase the amplitude of vibration.
- Use of an appropriate sensing mechanism to detect the distribution of silverware and vary the frequency of vibration accordingly to provide a more uniform output.

Improvements to Stage-01-B: Stage-01-B is reasonably well placed and working well. Expanding the magnetic area of influence to fit the width of the sheet will prevent the few silverware pieces that slide past. Furthermore the design of the sensors can be improved to increase singulating performance of the rig and its repeatability:

- Improvement in the manufacturing technique of the sensor is required. The method used herein to make these sensors renders them nondurable. Moreover, friction offered by these sensors sometimes prevents silverware pieces from sliding down the incline during the absence of a magnetic field.
- Closer spacing of the adjacent sensing wires is required to provide better feedback to the actuators. In theory, decreasing the wire spacing to less than the width of the piece with least cross sectional thickness would almost guarantee a precise and dependable feedback that can help sustain repeatable singulation

performance. Precise feedback, apart from sizes of silverware pieces, is the most important factor in preventing this apparatus from having jams at any location in the test rig. For this experiment, the sensing distance should be not greater than 1/32".

- In standard practice, the outer casings of motors and electromagnets are grounded, which we followed in this work. It is important to note that these casings are connected to the test rig, and the support structure of the rig is made entirely of metal. Accordingly, the entire structure of the rig should be grounded. When a silverware piece connects adjacent sensing lines on the sensor, it triggers a "high" in the microprocessor. But, if a silverware piece connects adjacent sensing lines and, at the same time, contacts any metallic part of the test rig, then the sensor sends a "low" signal to the microprocessor, causing the sensing mechanism to fail. Therefore, adequate care must be taken to insulate the metallic parts of the rig that are near and around the sensor area.
- One more solenoid might be added to the metering bin in Stage-02 to augment its performance whenever more than 25 silverware pieces fall into the metering bin.

<u>Improvements to Stage-02:</u> Stage-02 displayed very good performance in its present configuration. The only aspect of its design that needs to be revisited is the durability of duck cloth. An alternative to duck cloth that has same surface characteristics and better durability should be researched.

<u>Improvements to Sensor Design:</u> The copper sensing comb is a low cost yet effective sensor. However, it is not durable to silverware pieces falling on top of it. The sensing circuits on the inclined Masonite sheet were relatively more durable than the one on

metering bin. This is due to the fact that, on the inclined sheet, the silverware pieces were sliding on top of the sensing circuits whereas in the metering bin the pieces directly fell on top of the sensing lines thereby damaging them. A more robust sensing material to withstand the constant erosion by silverware pieces is required. Use of commercially designed circuits may be attempted to obtain the desired precision and durability. The search terms required to be used are “Flexible PCB”, “Screen printable Circuit Ink”. Also, experimentation with closely spaced narrow light bands may be suggested to find a durable, “non – contact” and precise sensing mechanism.

During test trials, on more than one occasion the rig singulated silverware pieces at a rate that exceeded 40 pieces/min. It is hoped that implementation of the above stated recommendations will help rig performance improve to 50 pieces/min, with 95% or better efficiency.

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APPENDICES

APPENDIX-A

ABSTRACTS OF PATENTS REVIEWED

United States Patent [19]

Weihe et al.

[11] **Patent Number: 4,954,250**

[45] **Date of Patent: Sep. 4, 1990**

[54] **FLATWARE SEPARATING APPARATUS**

[75] Inventors: **Clyde Weihe**, Needham Heights; **Lewis Maroti**, Melrose; **Peter Albertini**, Dover, all of Mass.

[73] Assignee: **Food Service Innovations, Inc.**, Dover, Mass.

[21] Appl. No.: **352,356**

[22] Filed: **May 16, 1989**

[51] **Int. Cl.**[5] **B07C 5/12**

[52] **U.S. Cl.** **209/629**; 209/632; 209/633; 209/644; 209/660; 209/673; 209/926; 209/932; 209/940

[58] **Field of Search** 209/44.1, 44.2, 557, 209/606, 615–618, 629, 632, 633, 644, 651–654, 656, 658, 659, 660, 667–669, 671, 673, 707, 911, 932, 940

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3,583,564	6/1971	Peters	209/616
4,635,798	1/1987	Bruck	209/940 X
4,750,621	6/1988	Akesson et al.	209/926 X

FOREIGN PATENT DOCUMENTS

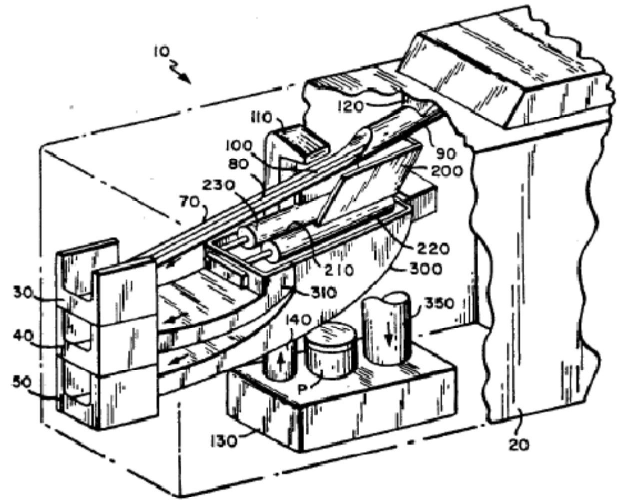
2042321	3/1972	Fed. Rep. of Germany	209/926
2915993	11/1979	Fed. Rep. of Germany	209/644

Primary Examiner—Johnny D. Cherry
Assistant Examiner—Edward M. Wacyra
Attorney, Agent, or Firm—M. Lawrence Oliverio

[57] **ABSTRACT**

A flatware separating apparatus comprising a track having a top surface for receiving and delivering different items of flatware along a selected path; a mechanism for contacting selected items of the flatware at a selected point along the path of the track and pushing the selected items off the surface of the track and allowing other selected items of the flatware to remain on the surface; and a mechanism for further separating the selected items of flatware pushed off the surface of the track.

39 Claims, 5 Drawing Sheets



US005996809A

United States Patent [19]

Chiasson

[11] Patent Number: 5,996,809

[45] Date of Patent: Dec. 7, 1999

[54] FLATWARE SORTING MACHINE

[76] Inventor: Robert H. Chiasson, c/o East Coast Industries, Inc. 2532 Main St., Concord, Mass. 01742

[21] Appl. No.: 08/852,088

[22] Filed: May 7, 1997

[51] Int. Cl.[6] B07C 5/344; B65G 17/32

[52] U.S. Cl. 209/636; 209/904; 209/919; 209/926; 198/443; 198/679; 198/681; 198/803.6

[58] Field of Search 209/636, 904, 209/907, 919, 926; 198/678.1, 679, 681, 690.1, 803.6, 443

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FOREIGN PATENT DOCUMENTS

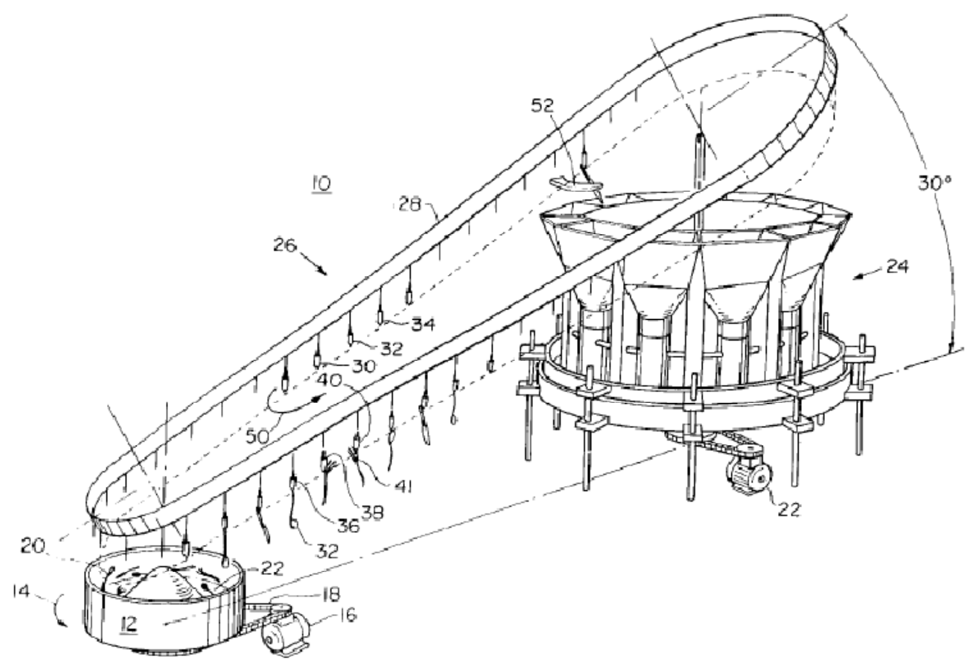
2170737 8/1986 United Kingdom 209/926

Primary Examiner—Tuan N. Nguyen
Attorney, Agent, or Firm—Iandiorio & Teska

[57] ABSTRACT

A flatware sorting machine including a feed bin for holding unsorted flatware, a sorting system for sorting the flatware, and a flatware pick-up and transport system for retrieving the flatware from the feed bin and transporting them to the sorting system.

16 Claims, 12 Drawing Sheets



APPENDIX-B

VENDOR MATERIAL QUOTE FOR SILVERWARE

QUOTE

Project:
OSU Student Union Central Rec
Student Union Attn Wayne Prater
117 SU;
Stillwater, OK 74078-0000
(405) 744-9860

From:
Penny Humphrey
Market Source Inc.
4525 N. Cooper
Oklahoma City, OK 73118
(800) 582-3325 x102 Fax: (405) 521-0273

To:
Wayne Prater
OSU Student Union
Student Union 17
Attn: Wayne Prater
Stillwater, OK 74078
(405) 744-7393

Item	Qty	Description		Sell Each	Sell Total
73 	9 dz	TEASPOON Trade Advantage Model No. FL-NDL-1 Teaspoon, 18-0 chrome, Pointelle 81230	50 dz per case	3.16	28.44
74 	9 dz	SPOON, BOUILLON Trade Advantage Model No. FL-NDL-2 Bouillon Spoon, 18-0 chrome, Pointelle 81270	50 dz per case	4.54	40.86
75 	9 dz	*** ALTERNATE *** ( ) DESSERT SPOON Trade Advantage Model No. FL-NDL-3 Oval Dessert Spoon, 18-0 chrome, Pointelle 81265	50 dz per case	4.80	alternate alternate
76 	9 dz	FORK, DINNER Trade Advantage Model No. FL-NDL-5 Dinner Fork, 18-0 chrome, Pointelle	50 dz per case	4.80	43.20

Item	Qty	Description	Sell Each	Sell Total
		81240		
77 	9 dz	KNIFE, DINNER Trade Advantage Model No. FL-NDL-7 25 dz per case Dinner Knife, 18-0 chrome, Pointelle	7.97	71.73
		81250		
78 	9 dz	*** ALTERNATE *** ( ) TEASPOON Trade Advantage Model No. FL-RIM-1 50 dz per case Teaspoon, 18-0 chrome, heavy-weight, Ridgely	8.12	alternate
		102600		alternate
79 	9 dz	*** ALTERNATE *** ( ) SPOON, BOUILLON Trade Advantage Model No. FL-RIM-2 50 dz per case Bouillon Spoon, 18-0 chrome, heavy-weight, Ridgely	9.17	alternate
		102610 OUT OF STOCK & ON BACK ORDER AT THE FACTORY		alternate alternate
80 	9 dz	*** ALTERNATE *** ( ) DESSERT SPOON Trade Advantage Model No. FL-RIM-3 50 dz per case Dessert Spoon, oval, 18-0 chrome, heavy-weight, Ridgely	11.91	alternate
		102620 OUT OF STOCK & ON BACKORDER AT THE FACTORY		alternate alternate
81 	9 dz	*** ALTERNATE *** ( ) FORK, DINNER Trade Advantage Model No. FL-RIM-5 50 dz per case Dinner Fork, 18-0 chrome, heavy-weight, Ridgely	11.91	alternate
		102640 OUT OF STOCK & ON BACKORDER AT THE FACTORY		alternate alternate

Item	Qty	Description	Sell Each	Sell Total
83 	9 dz	*** ALTERNATE *** ( ) KNIFE, DINNER Trade Advantage Model No. FL-RIM-7 25 dz per case Dinner Knife, 18-0 chrome, heavy-weight, Ridgely	17.01	alternate
		102660		alternate
			Total	184.23
			Grand Total	184.23

Pricing is good for 30 days.

All Pricing is plus applicable sales tax and freight.

Market Source Inc.

APPENDIX – C

DATASHEET OF MOTOR FOR VIBRATING BIN

IM-13 GEARMOTORS

DC Permanent Magnet Spur Gearmotors

E-2135

torque rating: Standard sintered gear strength to 100 oz. in. Wide-face sintered gear strength to 160 oz. in.

weight: 8 to 11 ounces

gears: Precision high density sintered steel

shaft: Precision-ground, through hardened AISI 1137-1141 steel. Options: length, flats, pinions, gears. Shaft material may change depending upon options selected

bearings: Motor and gearbox bearings are life-lubricated sleeve bearings. Ball bearing option available

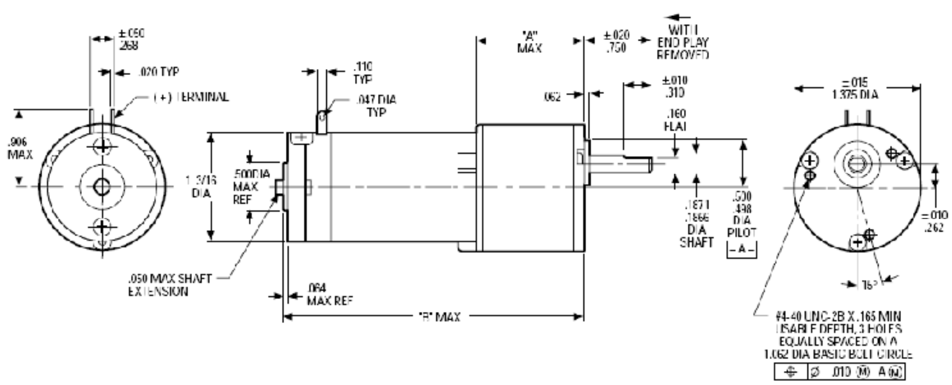
gearbox cover: Corrosion resistant aluminum housing

mounting flange: Die-cast zinc, coated to prevent oxidation

options available:

- Ball bearings
- Leads
- EMI suppression

Dimensions



ROTATION (SEE CHART, OPPOSITE PAGE) VIEWED FROM SHAFT END WITH POSITIVE VOLTAGE ON (+) TERMINAL. REVERSE POLARITY FOR OPPOSITE ROTATION

NOTE: Consult factory prior to preparing spec control prints. Dimensions are for reference only

Standard Part Numbers and Data
Standard Sintered Gearing

STANDARD PART NUMBER PREFIX*	DIMENSION "A" MAX (in.) (in.)	DIMENSION "B" MAX	REDUCTION RATIO	TORQUE MULTIPLIER	CONTINUOUS TORQUE -2* (oz. in.)	CONTINUOUS TORQUE -3* (oz. in.)	DIRECTION OF ROTATION
415A154	.960	2.794	6.30	5.35	8	8	CW
415A155	.960	2.794	9.99	7.85	12	12	CCW
415A156	.960	2.794	19.53	15.35	23	23	CCW
415A157	.960	2.794	30.96	22.35	31	31	CW
415A158	.960	2.794	60.54	43.71	66	66	CW
415A159	.960	2.794	95.97	64.11	96	96	CCW
415A160	.960	2.794	187.68	125.36	100	100**	CCW
415A161	1.186	3.020	297.52	182.67	100	100**	CW
415A162	1.186	3.020	581.82	357.22	100	100**	CW
415A163	1.186	3.020	922.31	522.93	100	100**	CCW
415A164	1.186	3.020	1,803.64	1,022.61	100	100**	CCW

Wide-face Sintered Gearing

STANDARD PART NUMBER PREFIX*	DIMENSION "A" MAX (In.) (In.)	DIMENSION "B" MAX	REDUCTION RATIO	TORQUE MULTIPLIER	CONTINUOUS TORQUE -2* (oz. In.)	CONTINUOUS TORQUE -3* (oz. In.)	DIRECTION OF ROTATION
415A176	1.186	3.020	19.53	15.35	23	23	CCW
415A177	1.186	3.020	30.52	22.35	34	34	CW
415A178	1.186	3.020	60.54	43.71	66	66	CW
415A179	1.186	3.020	94.60	64.11	96	96	CCW
415A180	1.186	3.020	187.68	125.36	160	160**	CCW
415A181	1.398	3.232	293.26	182.67	160	160**	CW
415A182	1.398	3.232	581.82	357.22	160	160**	CW
415A183	1.398	3.232	909.09	522.93	160	160**	CCW
415A184	1.398	3.232	1,803.61	1,022.61	160	160**	CCW

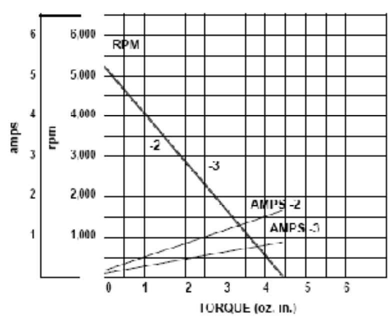
*When You Order

Each of the basic motor armature windings (bottom chart) can be used with any of the gear ratios listed above. To order, state the gear train standard part number prefix, plus a motor armature winding dash number. EXAMPLE: 415A154-2 is a 6.30:1 IM-13 gear train with a "-2" armature winding, 12 volts, 5,200 rpm, 1.50 oz. in. torque, etc.

** **NOTE:** 100 oz. in. is the maximum strength of this gearmotor series using standard sintered steel gears; 160 oz. in. is the maximum strength of this gearmotor series using wide-faced sintered gears. Damage may result if this torque is exceeded.

Typical Motor Performance

Dash 2 and 3 armature windings



Basic Motor Data

ARMATURE WINDING DASH NO.*	VOLTAGE (VDC)	SPEED ±10% NO LOAD (rpm)	CURRENT NO LOAD (max amps)	RATED TORQUE (oz. in.)	CURRENT AT RATED TORQUE (max amps)	TORQUE CONSTANT (oz. in./amps)	RESISTANCE (ohms)
-2	12	5,200	.230	1.50	.80	2.9	7.3
-3	24	5,200	.140	1.50	.40	5.6	30.0

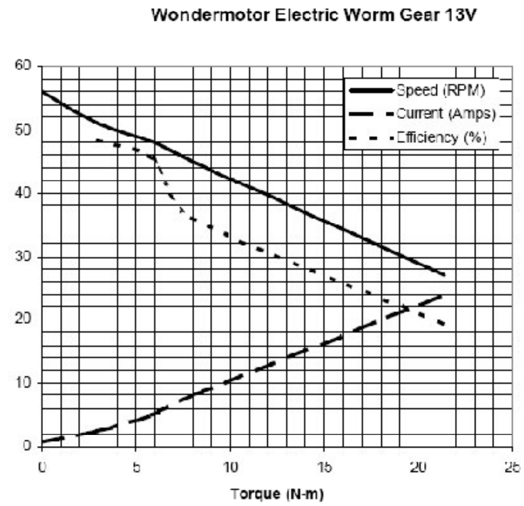
APPENDIX – D

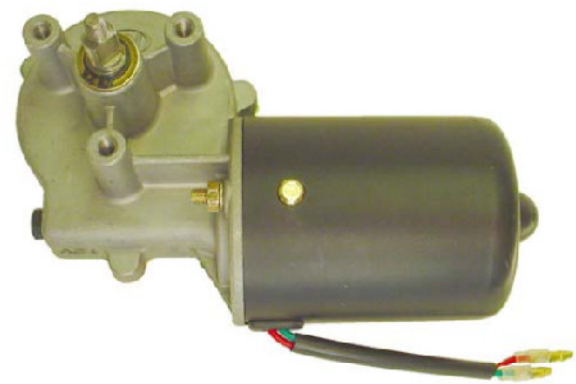
DATASHEET OF MOTOR FOR BELT DRIVE

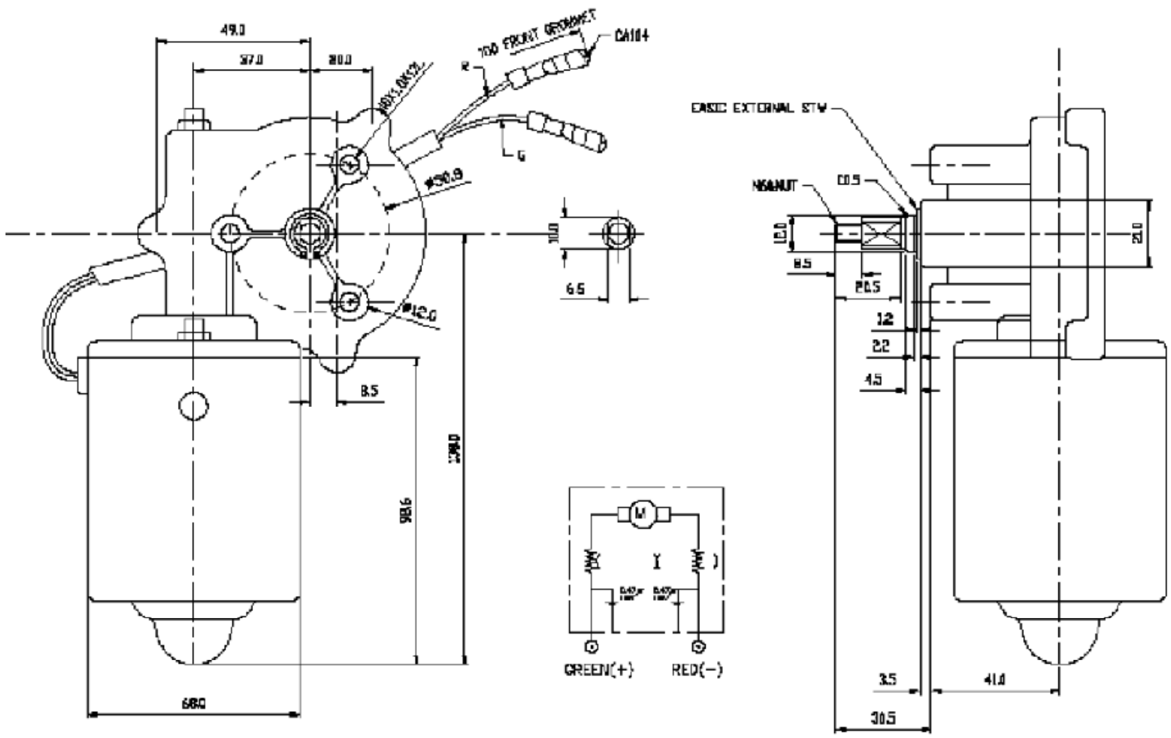
WONDERMOTOR

YOUR SOURCE OF HIGH QUALITY MOTORS

| E-mail: sales@wondermotor.com | | Phone: 626.322.9220 |







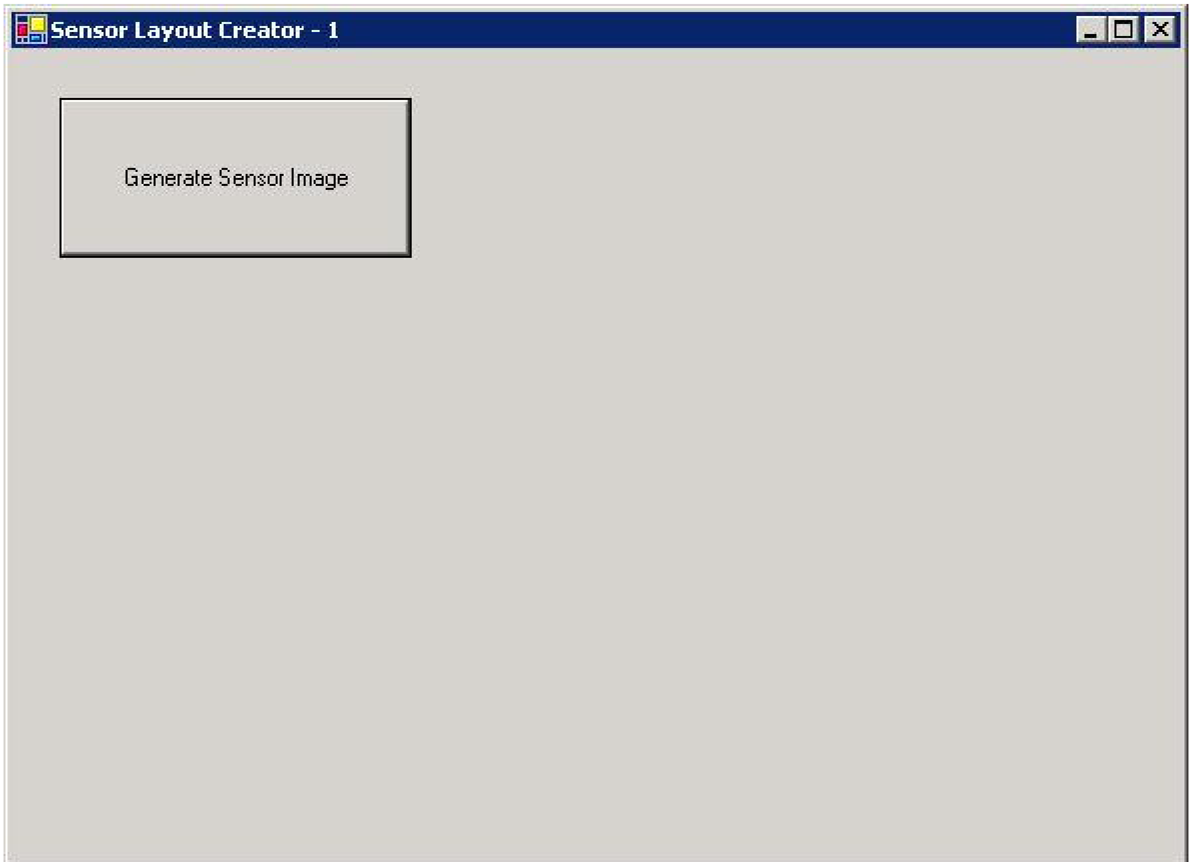
APPENDIX E

VB.NET CODE FOR SENSOR DESIGN

```vb
Imports System.Drawing
Imports System.Drawing.Imaging
Imports System.Drawing.Drawing2D
Public Class Form1
   Inherits System.Windows.Forms.Form
#Region " Windows Form Designer generated code "
   Public Sub New()
      MyBase.New()
      'This call is required by the Windows Form Designer.
      InitializeComponent()
      'Add any initialization after the InitializeComponent() call
   End Sub
   'Form overrides dispose to clean up the component list.
   Protected Overloads Overrides Sub Dispose(ByVal disposing As Boolean)
      If disposing Then
         If Not (components Is Nothing) Then
            components.Dispose()
         End If
      End If
      MyBase.Dispose(disposing)
   End Sub
   'Required by the Windows Form Designer
   Private components As System.ComponentModel.IContainer
   'NOTE: The following procedure is required by the Windows Form Designer
   'It can be modified using the Windows Form Designer.
   'Do not modify it using the code editor.
   Friend WithEvents Button1 As System.Windows.Forms.Button
   <System.Diagnostics.DebuggerStepThrough()> Private Sub InitializeComponent()
      Me.Button1 = New System.Windows.Forms.Button
      Me.SuspendLayout()
      '
      'Button1
      '
      Me.Button1.Location = New System.Drawing.Point(24, 24)
      Me.Button1.Name = "Button1"
      Me.Button1.Size = New System.Drawing.Size(176, 80)
      Me.Button1.TabIndex = 0
      Me.Button1.Text = "Generate Sensor Image"
      '
      'Form1
      '
      Me.AutoScaleBaseSize = New System.Drawing.Size(5, 13)
      Me.ClientSize = New System.Drawing.Size(584, 405)
```

```
        Me.Controls.Add(Me.Button1)
        Me.Name = "Form1"
        Me.Text = "Sensor Layout Creator - 1"
        Me.ResumeLayout(False)
    End Sub
#End Region
    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs)
Handles Button1.Click
        Dim B_obj As Bitmap
        Dim G_obj As Graphics
        Dim ff As New SaveFileDialog
        Dim dpi As Single
        Dim mm2inch As Single
        Dim inch2mm As Single
        Dim im_ww As Integer
        Dim im_hh As Integer
        Dim wire_th As Integer
        Dim space_th As Integer
        Dim n1  As Integer
        Dim i, j, k As Integer
        Dim cx, cy As Single
        Dim act_ww As Single
        Dim act_hh As Single
        Dim pen_ww As Single
        Dim space_ww As Single
        Dim fss As String
        Dim ss1, ss2, ss3, ss4 As String
        dpi = 600
        mm2inch = 1.0 / 25.4
        inch2mm = 25.4
        'act_ww = 76.2 ' mm
        'act_hh = 76.2 ' mm
        act_ww = 10 * inch2mm ' mm
        act_hh = 6 * inch2mm ' mm
        pen_ww = (1 / 16) * inch2mm ' mm
        space_ww = (1 / 16) * inch2mm ' mm
        im_ww = Math.Round(act_ww * mm2inch * dpi)
        im_hh = Math.Round(act_hh * mm2inch * dpi)
        wire_th = Math.Round(pen_ww * mm2inch * dpi)
        space_th = Math.Round(space_ww * mm2inch * dpi)
        B_obj = New Bitmap(im_ww, im_hh, PixelFormat.Format32bppRgb)
        B_obj.SetResolution(dpi, dpi)
        n1 = Math.Floor(im_hh / (2.0 * (wire_th + space_th)))
```

```
        For i = 0 To (im_ww - 1)
            For j = 0 To (im_hh - 1)
                B_obj.SetPixel(i, j, Color.White)
            Next
        Next
        For i = 0 To n1 - 1
            For j = 0 To wire_th - 1
                cx = (i * 2 * (wire_th + space_th)) + j
                For k = 0 To (im_ww - (space_th + wire_th) - 1)
                    B_obj.SetPixel(k, cx, Color.Gray)
                Next
            Next
        Next
        For i = 0 To n1 - 1
            For j = 0 To wire_th - 1
                cx = (wire_th + space_th) + (i * 2 * (wire_th + space_th)) + j
                For k = ((space_th + wire_th) - 1) To (im_ww - 1)
                    B_obj.SetPixel(k, cx, Color.Gray)
                Next
            Next
        Next
        For i = 0 To im_hh - 1
            For j = 0 To wire_th - 1
                B_obj.SetPixel(j, i, Color.Gray)
            Next
        Next
        For i = 0 To im_hh - 1
            For j = (im_ww - wire_th - 1) To im_ww - 1
                B_obj.SetPixel(j, i, Color.Gray)
            Next
        Next
        If ff.ShowDialog = DialogResult.OK Then
            B_obj.Save(ff.FileName, ImageFormat.Bmp)
        End If
        ss1 = "Sensor Strips needed : " & Trim(Str(2 * n1))
        MsgBox(ss1)
        B_obj.Dispose()
        Me.Close()
    End Sub
End Class
```


Sensor Layout Creator - 1
Generate Sensor Image

APPENDIX F

PIC C CODE FOR SINGULATION MECHANISM

```
#include<16f876a.h>
#include<string.h>
#fuses HS,NOLVP,NOWDT,PUT
#use delay(clock=20000000)
#use rs232(baud=38400, parity=N, xmit=PIN_C6, rcv=PIN_C7,stream=HOSTPC)

// ----------------------------------------------------------------------

#define MOTOR_PIN            PIN_C0
#define UPPER_MAGNET_PIN     PIN_C1
#define LOWER_MAGNET_PIN     PIN_C2
#define SHEET_SOLENOID_PIN   PIN_C3

#define UM_SENSOR_PIN        PIN_A0
#define LM_SENSOR_PIN        PIN_A1
#define SH_SENSOR_PIN        PIN_A2

// ----------------------------------------------------------------------

#define ON 1
#define OFF 0

#define OBJ_PRESENT 1
```

```
#define OBJ_ABSENT 0
#define MOTOR_DISPENSE 1
#define MOTOR_BLOCK 0

#define MAGNET_DISPENSE 0
#define MAGNET_BLOCK 1

#define SOLENOID_PULSE 1
#define SOLENOID_REST 0

#define SIGNAL_DELAY 250

#define MOTOR_ON  {output_high(MOTOR_PIN);delay_us(SIGNAL_DELAY);}
#define MOTOR_OFF {output_low(MOTOR_PIN);delay_us(SIGNAL_DELAY);}
#define UPPER_MAGNET_ON
{output_high(UPPER_MAGNET_PIN);delay_us(SIGNAL_DELAY);}
#define UPPER_MAGNET_OFF
{output_low(UPPER_MAGNET_PIN);delay_us(SIGNAL_DELAY);}
#define LOWER_MAGNET_ON
{output_high(LOWER_MAGNET_PIN);delay_us(SIGNAL_DELAY);}
#define LOWER_MAGNET_OFF
{output_low(LOWER_MAGNET_PIN);delay_us(SIGNAL_DELAY);}
#define SHEET_SOLENOID_ON
{output_high(SHEET_SOLENOID_PIN);delay_us(SIGNAL_DELAY);}
#define SHEET_SOLENOID_OFF
{output_low(SHEET_SOLENOID_PIN);delay_us(SIGNAL_DELAY);}
```

```
#define UM_SENSOR_STATUS input(UM_SENSOR_PIN)
#define LM_SENSOR_STATUS input(LM_SENSOR_PIN)
#define SH_SENSOR_STATUS input(SH_SENSOR_PIN)

#define SOME_DELAY delay_us(1000)
#define MAGNET_RELEASE_DELAY delay_ms(200)
#define SHEET_SOLENOID_DELAY delay_ms(100)

int ss=0,mm=0,hh=0;
int time_scale1 = 0;
long time_count=0;
int um_s,lm_s,sh_s;
long um_count=0,lm_count=0,sh_count=0,tt_count=0;
int um_state,lm_state,mm_state,sh_state;
int um_phy_state, lm_phy_state, sh_phy_state;
int em_counter_1 = 0;
int n_em_1 = 0;

void test_interface();
void pulse_system();
// ----------------------------------------------------------------------

#INT_TIMER0
void timer0_isr()
{
set_timer0(100); // timer overflows every 10ms ....
```

```
time_count++;
if (time_count==1000)
  {
  time_count = 0;
  ss=ss+1;
  if (ss==60)
      {
      ss=0;
      mm=mm+1;
      if (mm==60)
        {
        mm=0;
        hh=hh+1;
        }
      }
  }
}


#INT_TIMER1
void timer1_isr()
{
set_timer1(3036); // timer overflows every 100ms ....
time_scale1 = time_scale1 + 1;


if (sh_count>(tt_count - sh_count)) sh_s = OBJ_PRESENT; else sh_s = OBJ_ABSENT;
```

```
if (um_count>(tt_count - um_count)) um_s = OBJ_PRESENT; else um_s = OBJ_ABSENT;

if (lm_count>(tt_count - lm_count)) lm_s = OBJ_PRESENT; else lm_s = OBJ_ABSENT;



lm_count = 0;

um_count = 0;

sh_count = 0;

tt_count = 0;



fprintf(HOSTPC,"\n\rUM : %d || LM : %d || SH : %d",um_s,lm_s,sh_s);



if ((um_s == OBJ_ABSENT) && (lm_s == OBJ_ABSENT) && (sh_s == OBJ_ABSENT)) {mm_state = MOTOR_DISPENSE; um_state = MAGNET_DISPENSE; lm_state = MAGNET_DISPENSE;}

else if ((um_s == OBJ_ABSENT) && (lm_s == OBJ_ABSENT) && (sh_s == OBJ_PRESENT)) {mm_state = MOTOR_DISPENSE; um_state = MAGNET_DISPENSE; lm_state = MAGNET_BLOCK;}

else if ((um_s == OBJ_ABSENT) && (lm_s == OBJ_PRESENT) && (sh_s == OBJ_ABSENT)) {mm_state = MOTOR_DISPENSE; um_state = MAGNET_BLOCK; lm_state = MAGNET_DISPENSE;}

else if ((um_s == OBJ_ABSENT) && (lm_s == OBJ_PRESENT) && (sh_s == OBJ_PRESENT)) {mm_state = MOTOR_DISPENSE; um_state = MAGNET_BLOCK; lm_state = MAGNET_BLOCK;}

else if ((um_s == OBJ_PRESENT) && (lm_s == OBJ_ABSENT) && (sh_s == OBJ_ABSENT)) {mm_state = MOTOR_BLOCK; um_state = MAGNET_DISPENSE; lm_state = MAGNET_DISPENSE;}

else if ((um_s == OBJ_PRESENT) && (lm_s == OBJ_ABSENT) && (sh_s == OBJ_PRESENT)) {mm_state = MOTOR_BLOCK; um_state = MAGNET_DISPENSE; lm_state = MAGNET_BLOCK;}
```

```
else if ((um_s == OBJ_PRESENT) && (lm_s == OBJ_PRESENT) && (sh_s == OBJ_ABSENT)) {mm_state = MOTOR_BLOCK; um_state = MAGNET_BLOCK; lm_state = MAGNET_DISPENSE;}

else if ((um_s == OBJ_PRESENT) && (lm_s == OBJ_PRESENT) && (sh_s == OBJ_PRESENT)) {mm_state = MOTOR_BLOCK; um_state = MAGNET_BLOCK; lm_state = MAGNET_BLOCK;}


if ((um_s == OBJ_PRESENT)&&(um_state == MAGNET_DISPENSE))
  {
  em_counter_1 = em_counter_1 + 1;
  if (em_counter_1 >= 30)    // 30 * 100ms ....
      {
      fprintf(HOSTPC,"\n\rSystem Exception 1 ....");
      mm_state = MOTOR_DISPENSE;
      em_counter_1 = 0;
      n_em_1 = n_em_1 + 1;
      }
  }
else
  {
  em_counter_1 = 0;
  }


if (sh_s == OBJ_PRESENT) sh_state = SOLENOID_PULSE; else sh_state = SOLENOID_REST;

if (mm_state == MOTOR_DISPENSE) {MOTOR_ON;} else {MOTOR_OFF;}


if (time_scale1 == 5)  // 5 * 100ms ....
```

```
{
time_scale1 = 0;
// upper magnet pulsing ...
if (um_state == MAGNET_DISPENSE)
   {
   um_phy_state = 1 - um_phy_state;
   if (um_phy_state == ON) {UPPER_MAGNET_ON;} else
{UPPER_MAGNET_OFF;}
   }
else
   {
   um_phy_state = ON;
   UPPER_MAGNET_ON;
   }


// upper magnet pulsing ...
if (lm_state == MAGNET_DISPENSE)
   {
   lm_phy_state = 1 - lm_phy_state;
   if (lm_phy_state == ON) {LOWER_MAGNET_ON;} else
{LOWER_MAGNET_OFF;}
   }
else
   {
   lm_phy_state = ON;
   LOWER_MAGNET_ON;
```

```
      }
  }


// solenoid pulsing logic ....
if (sh_state == SOLENOID_PULSE)
  {
  sh_phy_state = 1 - sh_phy_state;
  if (sh_phy_state == ON) {SHEET_SOLENOID_ON;} else {SHEET_SOLENOID_OFF;}
  }
else
  {
  sh_phy_state = OFF;
  SHEET_SOLENOID_OFF;
  }
}


void main()
{
int done=0;


set_tris_a(0x3f);      // all A pins are input ...
set_tris_b(0xff);      // all B pins are input ...
set_tris_c(0xB0);      // C7 input .... C0-C3 output .... C4,C5 .... input ... C6 output


fprintf(HOSTPC,"\n\n\n\r-----------------------------------------------------------");
```

```
fprintf(HOSTPC,"\n\rProgram Started !! .... \n\n\r");

test_interface();

fprintf(HOSTPC,"\n\n\n\r~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
~~~~~~~~~~~~");


setup_timer_1(T1_INTERNAL|T1_DIV_BY_8);

setup_timer_0(RTCC_INTERNAL|RTCC_DIV_32);

enable_interrupts(INT_TIMER1);

enable_interrupts(INT_TIMER0);

enable_interrupts(GLOBAL);

set_timer1(3036);

set_timer0(100);


fprintf(HOSTPC,"\n\rSingulation Started ... Press ESC to quit.\n\n\r\n\n");


mm_state = MOTOR_DISPENSE;

um_state = MAGNET_BLOCK;

lm_state = MAGNET_BLOCK;

sh_state = SOLENOID_REST;


sh_phy_state = OFF;

um_phy_state = ON;

lm_phy_state = ON;


SHEET_SOLENOID_OFF;

UPPER_MAGNET_ON;
```

```
LOWER_MAGNET_ON;

while(done==0)
  {
    if (kbhit()) {if (getc()==27) break;}
    sh_count = sh_count + SH_SENSOR_STATUS;
    lm_count = lm_count + LM_SENSOR_STATUS;
    um_count = um_count + UM_SENSOR_STATUS;
    tt_count = tt_count + 1;
  }

MOTOR_OFF;
UPPER_MAGNET_OFF;
LOWER_MAGNET_OFF;
SHEET_SOLENOID_OFF;

fprintf(HOSTPC,"\n\n\rSingulation Process took : %d hrs %d mins %d seconds",hh,mm,ss);
fprintf(HOSTPC,"\n\rSystem Exception 1 invoked : %d times",n_em_1);
fprintf(HOSTPC,"\n\r--------\n\n\r");
// end of main
}

void pulse_system()
{
int i;
```

```
for(i=0;i<30;i++)
  {
  fprintf(HOSTPC,"\n\rPulsing System ...");
  MOTOR_ON;
  UPPER_MAGNET_ON;
  LOWER_MAGNET_ON;
  SHEET_SOLENOID_ON;
  delay_ms(80);
  MOTOR_OFF;
  UPPER_MAGNET_OFF;
  LOWER_MAGNET_OFF;
  SHEET_SOLENOID_OFF;
  delay_ms(20);
  }
}

void test_interface()
{
char xx[10];
char s1[3]="mm";
char s2[3]="um";
char s3[3]="lm";
char s4[3]="sh";
char s5[3]="xx";
char s6[5]="doit";
char s7[6]="pulse";
```

```
char s8[3]="ss";
char s_on[3] = "on";
char s_off[4] = "off";
int i1,i2,i3;
int done=0;

fprintf(HOSTPC,"\n\rInterface module active. Type DOIT to start singulation.");

while(done==0)
  {
  fprintf(HOSTPC,"\n\r>>> : ");fgets(xx,HOSTPC);
  if (strstr(xx,s_on))
      {
      if (strstr(xx,s1)) MOTOR_ON;
      if (strstr(xx,s2)) UPPER_MAGNET_ON;
      if (strstr(xx,s3)) LOWER_MAGNET_ON;
      if (strstr(xx,s4)) SHEET_SOLENOID_ON;
      }
  else if (strstr(xx,s_off))
      {
      if (strstr(xx,s1)) MOTOR_OFF;
      if (strstr(xx,s2)) UPPER_MAGNET_OFF;
      if (strstr(xx,s3)) LOWER_MAGNET_OFF;
      if (strstr(xx,s4)) SHEET_SOLENOID_OFF;
      }
  else if (strstr(xx,s7))
```

```
    {
    i1 = 0;
    fprintf(HOSTPC,"\n\rPulsing Solenoid ... Press ESC to quit ...");
    while(i1==0)
     {
     SHEET_SOLENOID_ON;
     SHEET_SOLENOID_DELAY;
     SHEET_SOLENOID_OFF;
     SHEET_SOLENOID_DELAY;
     if (kbhit())
        {
        if (getc()==27) i1=1;
        }
     }
    fprintf(HOSTPC,"\n\rPulsing Solenoid complete \n\n\r");
    }
else if (strstr(xx,s6))
    {
    done=1;
    }
else if (strstr(xx,s8))
    {
    i1=0;
    while(i1==0)
     {
```

```
      fprintf(HOSTPC,"\n\rUM : %d || LM : %d || SS : %d",UM_SENSOR_STATUS,LM_SENSOR_STATUS,SH_SENSOR_STATUS);
      if (kbhit())
         {
         if (getc()==27) i1=1;
         }
      }
    }
  }
}
```

APPENDIX G

PIN DIAGRAM – PIC 16F876A

MICROCHIP

PIC16F87XA

28/40-Pin Enhanced FLASH Microcontrollers

Devices Included in this Data Sheet:

- PIC16F873A
- PIC16F874A
- PIC16F876A
- PIC16F877A

High Performance RISC CPU:

- Only 35 single word instructions to learn
- All single cycle instructions except for program branches, which are two-cycle
- Operating speed: DC - 20 MHz clock input
DC - 200 ns instruction cycle
- Up to 8K x 14 words of FLASH Program Memory, Up to 368 x 8 bytes of Data Memory (RAM), Up to 256 x 8 bytes of EEPROM Data Memory
- Pinout compatible to other 28-pin or 40/44-pin PIC16CXXX and PIC16FXXX microcontrollers

Peripheral Features:

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during SLEEP via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. resolution is 10-bit
- Synchronous Serial Port (SSP) with SPI™ (Master mode) and I²C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) 8-bits wide, with external $\overline{RD}$, $\overline{WR}$ and $\overline{CS}$ controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

Analog Features:

- 10-bit, up to 8 channel Analog-to-Digital Converter (A/D)
- Brown-out Reset (BOR)
- Analog Comparator module with:
  - Two analog comparators
  - Programmable on-chip voltage reference (V_{REF}) module
  - Programmable input multiplexing from device inputs and internal voltage reference
  - Comparator outputs are externally accessible

Special Microcontroller Features:

- 100,000 erase/write cycle Enhanced FLASH program memory typical
- 1,000,000 erase/write cycle Data EEPROM memory typical
- Data EEPROM Retention > 40 years
- Self-reprogrammable under software control
- In-Circuit Serial Programming™ (ICSP™) via two pins
- Single supply 5V In-Circuit Serial Programming
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code protection
- Power saving SLEEP mode
- Selectable oscillator options
- In-Circuit Debug (ICD) via two pins

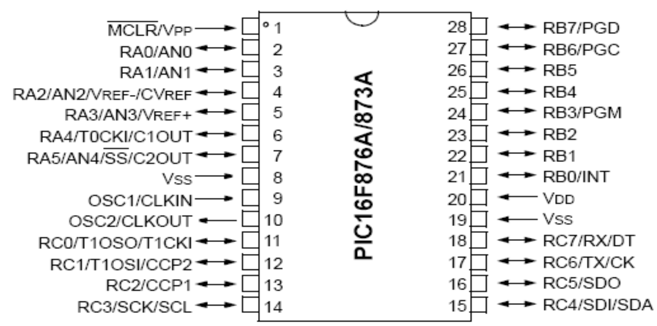
CMOS Technology:

- Low power, high speed FLASH/EEPROM technology
- Fully static design
- Wide operating voltage range (2.0V to 5.5V)
- Commercial and Industrial temperature ranges
- Low power consumption

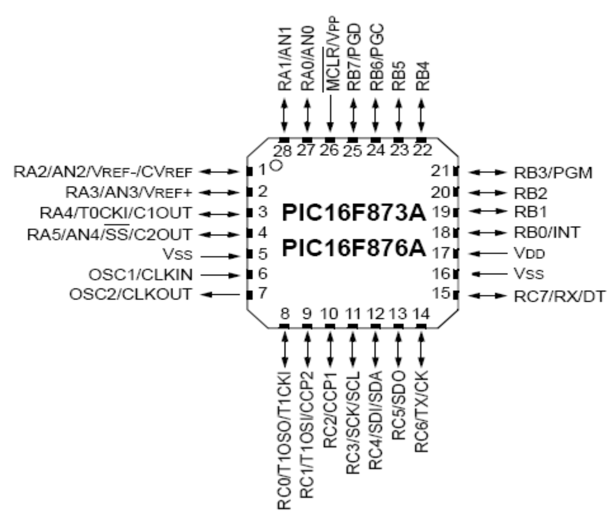
Device	Program Memory		Data SRAM (Bytes)	EEPROM (Bytes)	I/O	10-bit A/D (ch)	CCP (PWM)	MSSP		USART	Timers 8/16-bit	Comparators
	Bytes	# Single Word Instructions						SPI	Master I²C			
PIC16F873A	7.2K	4096	192	128	22	5	2	Yes	Yes	Yes	2/1	2
PIC16F874A	7.2K	4096	192	128	33	8	2	Yes	Yes	Yes	2/1	2
PIC16F876A	14.3K	8192	368	256	22	5	2	Yes	Yes	Yes	2/1	2
PIC16F877A	14.3K	8192	368	256	33	8	2	Yes	Yes	Yes	2/1	2

Pin Diagrams

PDIP (28-pin), SOIC, SSOP



MLF

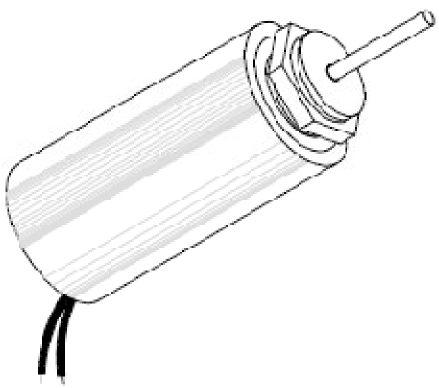


APPENDIX – H

DATASHEET FOR THE SOLENOID

MAGNETIC SENSOR SYSTEMS

Push Type Tubular Solenoid



Series S-25-125-H

1 1/4" DIA X 2 1/2"

TOTAL WEIGHT: 11.2 OUNCES
PLUNGER WEIGHT: 1.5 OUNCES

duty cycle	1	1/2	1/4	1/10
maximum "ON" time, (Sec.)	∞	410	100	30
watts	11	22	44	110
approximate ampere turns	1410	2000	2820	4460

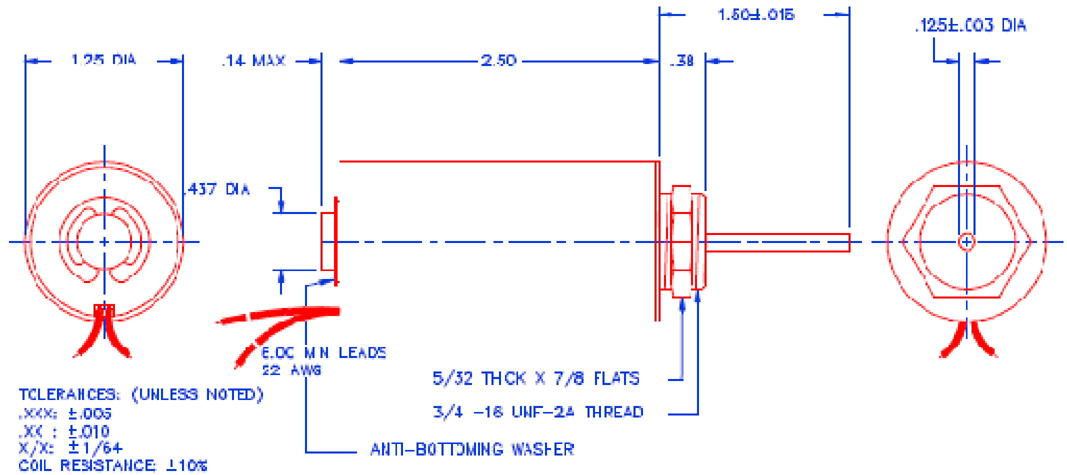
AWG number	resistance	volts DC	volts DC	volts DC	volts DC
20	0.97	3.2	4.5	6.3	10.0
21	1.38	4.0	5.6	7.9	12.5
22	2.49	5.1	7.2	10.2	16.1
23	3.49	6.2	8.8	12.5	19.7
24	6.06	8.1	11.5	16.2	25.5
25	9.89	10.3	14.5	20.5	32.4
26	16.6	13.0	18.4	25.9	41.0
27	24.5	16.1	22.8	32.2	50.9
28	36.9	20.4	28.9	40.8	64.5
29	61.8	25.5	36.1	51.0	80.6
30	93.3	31.5	44.6	62.9	99.5
31	144	40.3	57.1	80.6	127
32	210	49.4	70.0	98.7	156
33	357	63.5	90.0	127	201
34	553	82	116	164	259
35	993	105	149	210	332
36	1460	131	186	263	415
37	2406	160	227	320	506

HEAT SINK: For proper heat dissipation, body of solenoid should be mounted on an equivalent of 6.0" x 6.0" x 1/8" aluminum plate in an unrestricted flow of air.

6901 Woodley Avenue, Van Nuys, California 91406
Telephone: (818) 785-6244 Fax: (818) 785-5713
www.solenoidcity.com

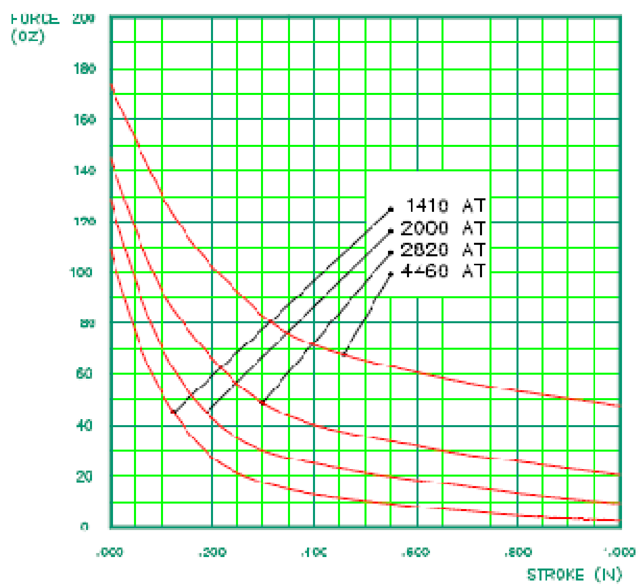
MAGNETIC SENSOR SYSTEMS

S-25-125-H MECHANICAL DIMENSIONS



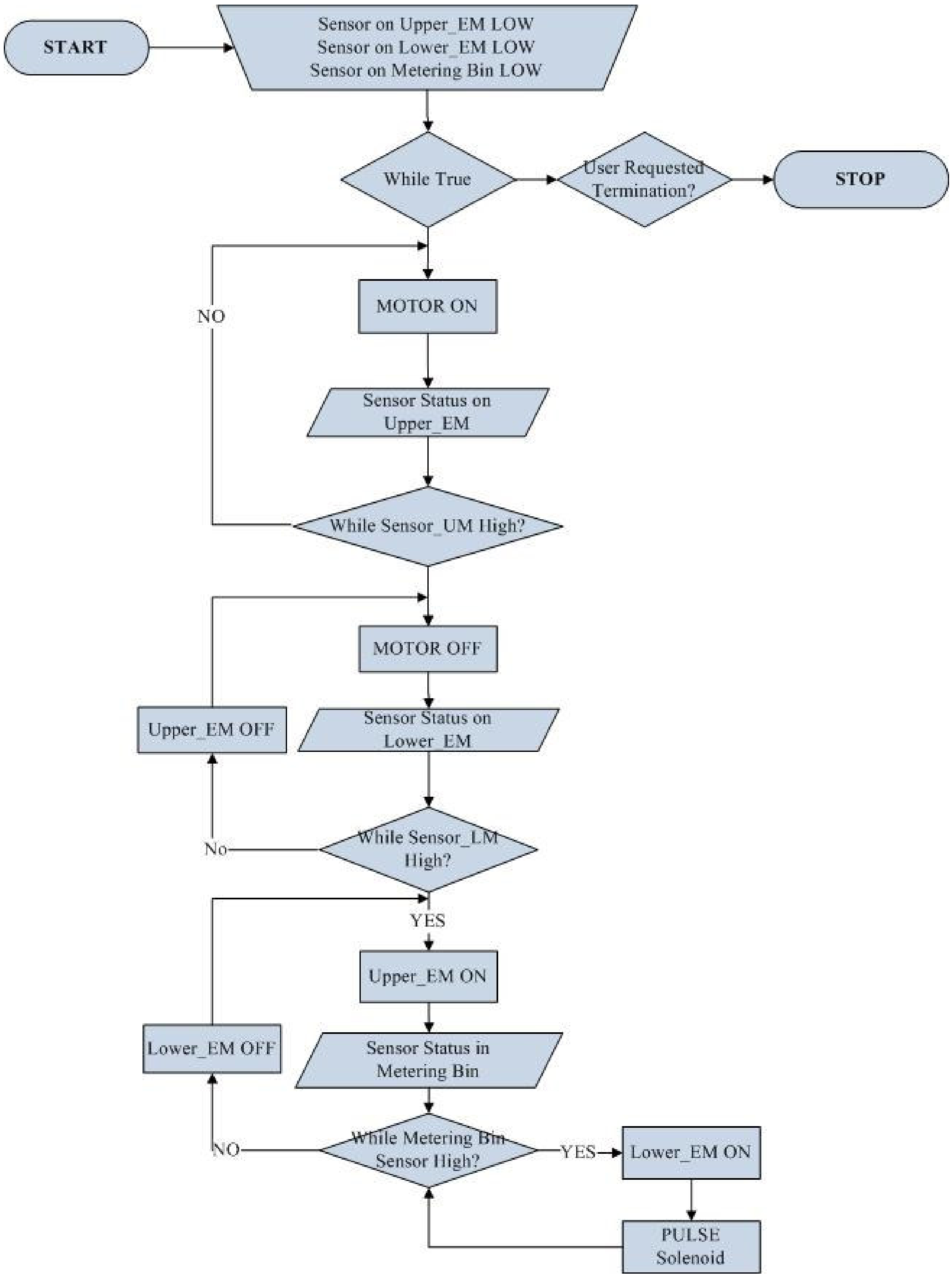
SOLENOID SHOWN ENERGIZED

TYPICAL PUSH FORCE VERSUS STROKE

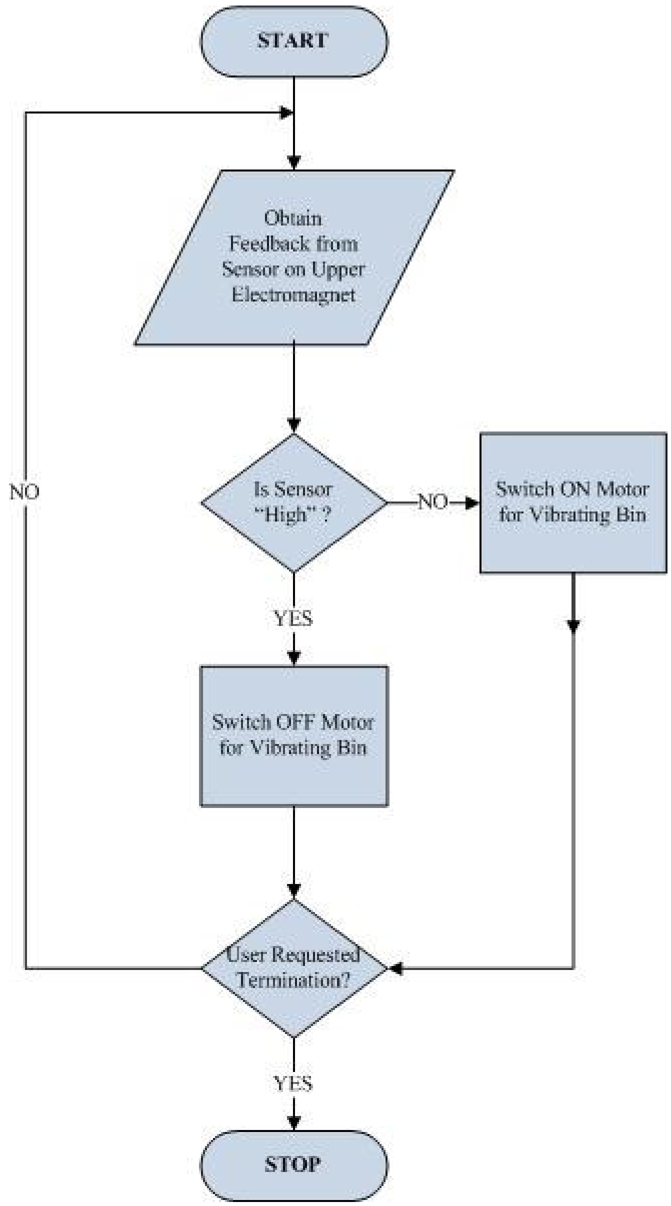


APPENDIX – I

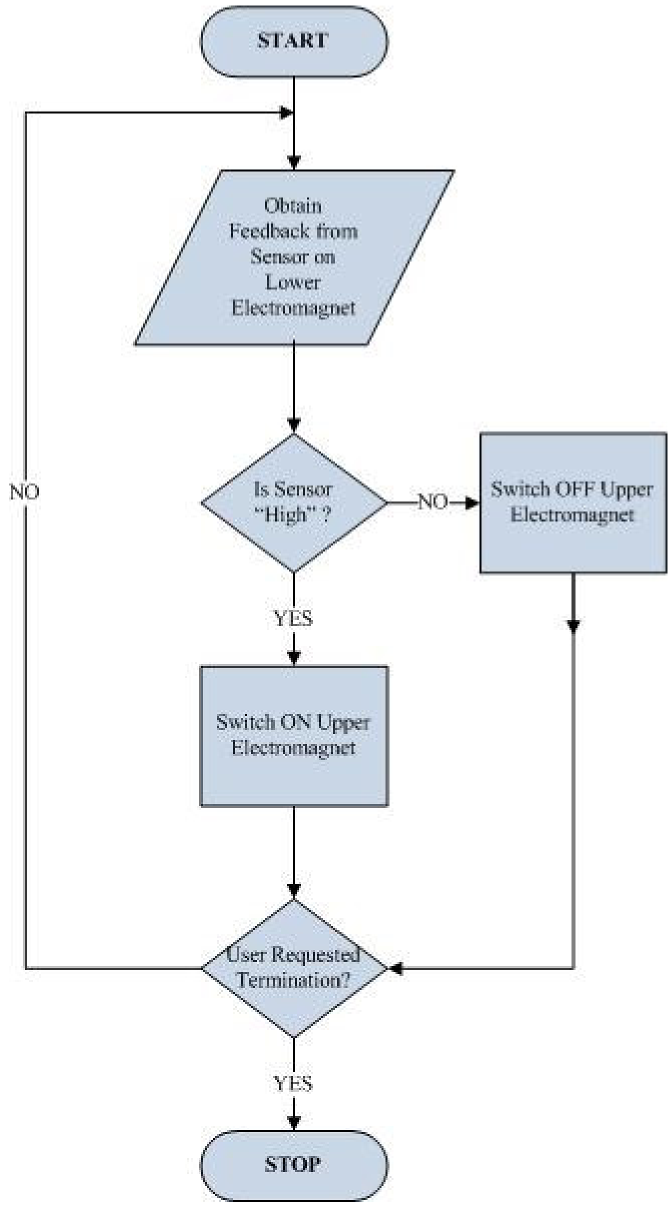
FLOWCHARTS FOR SINGULATION PROCESS



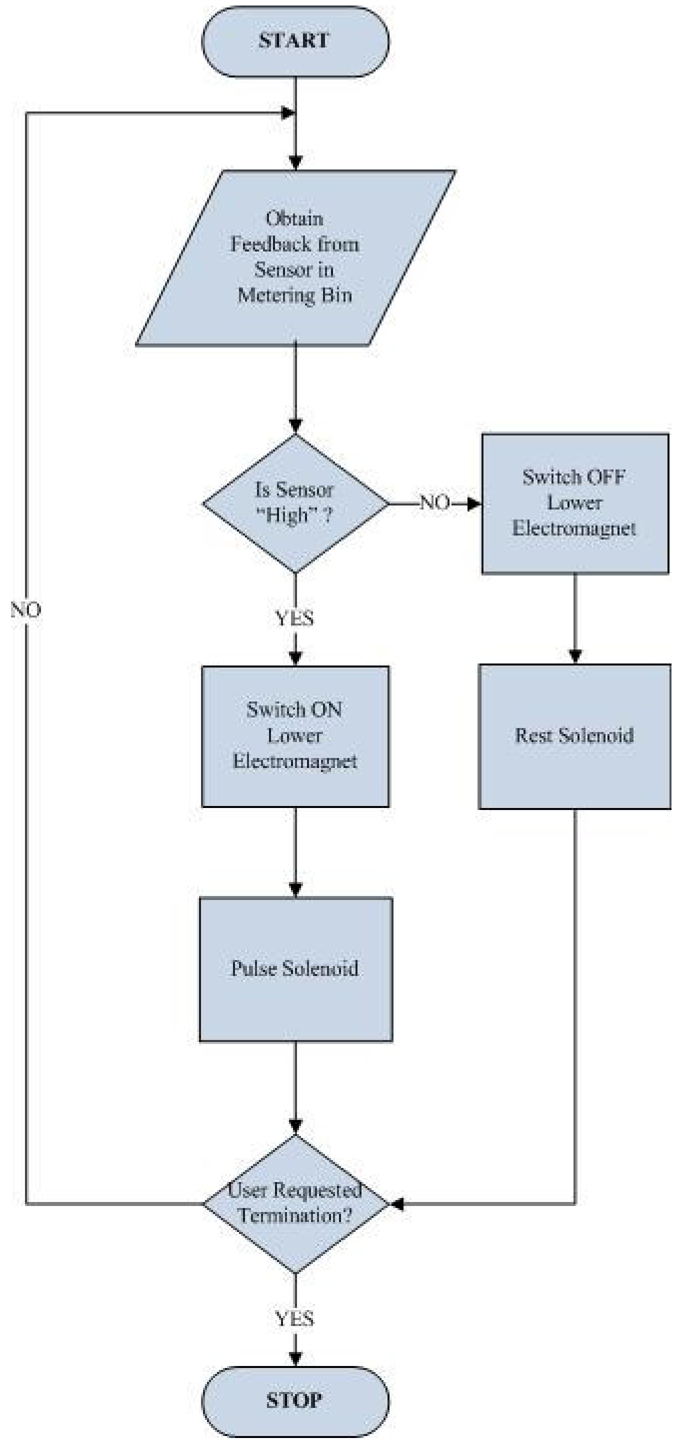
Flowchart for Singulation Process – Serial Approach



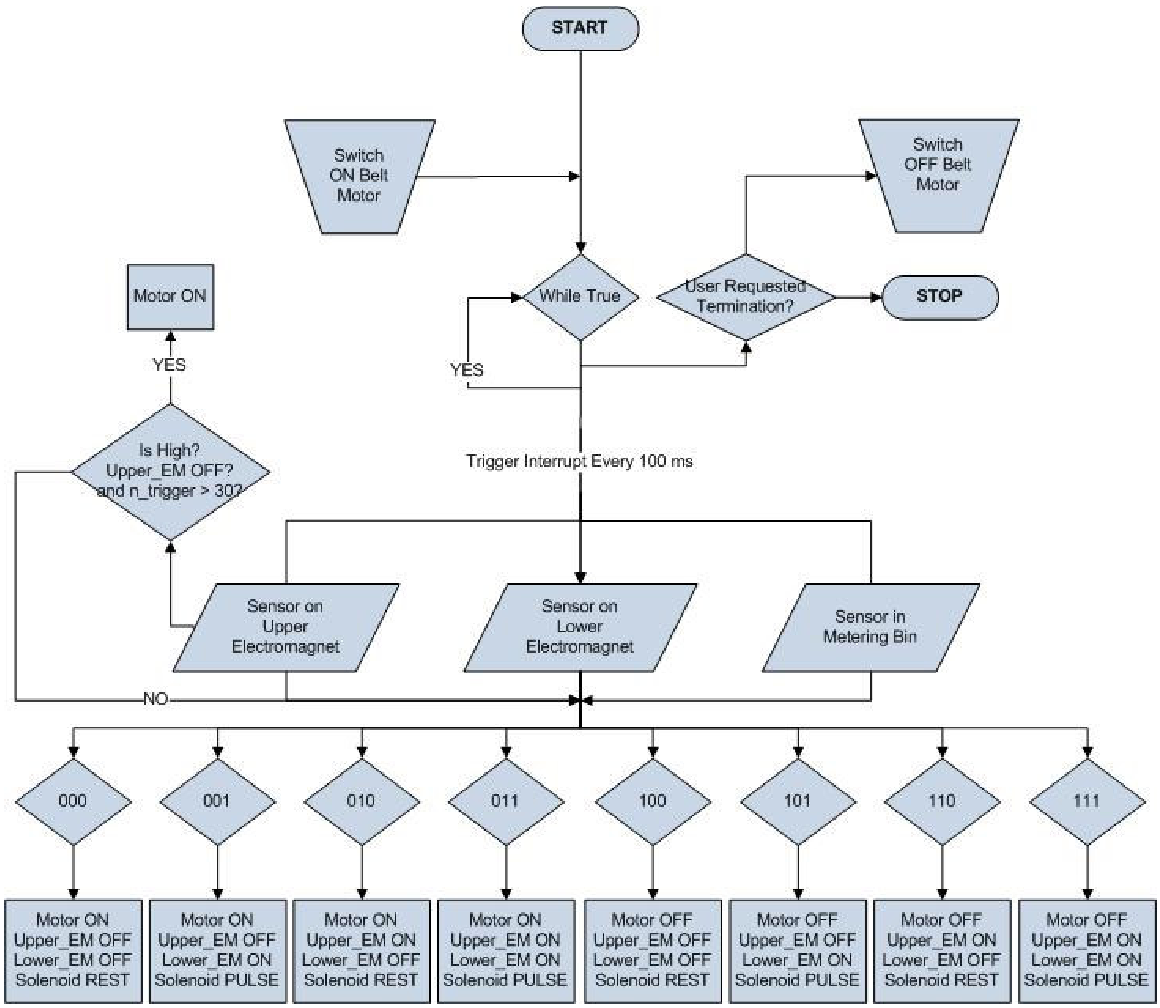
Flowchart for Motor of Vibrating Bin – Parallel Approach



Flowchart for Electromagnet 01 – Parallel Approach



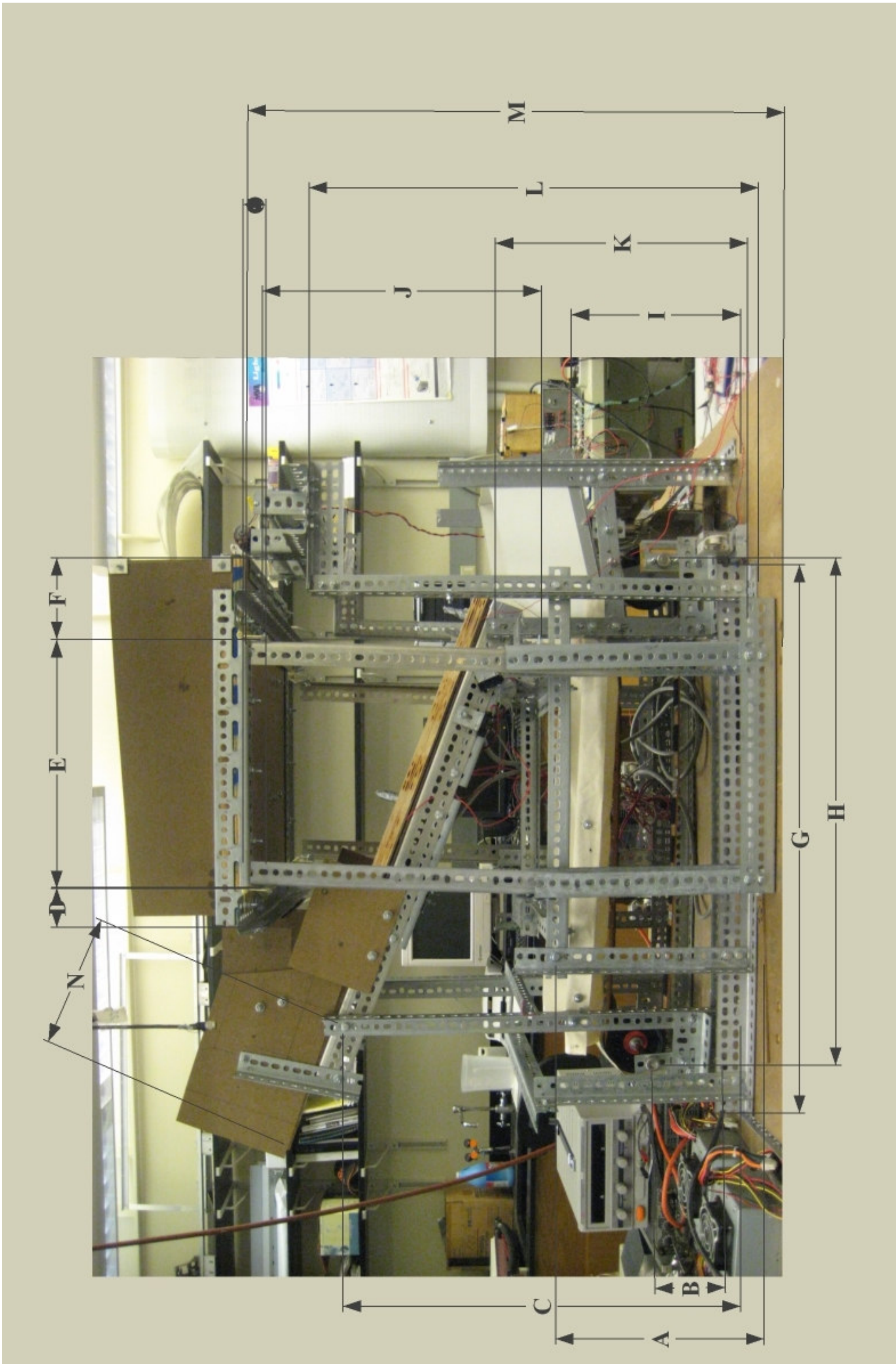
Flowchart for Electromagnet 02 and Solenoid – Parallel Approach



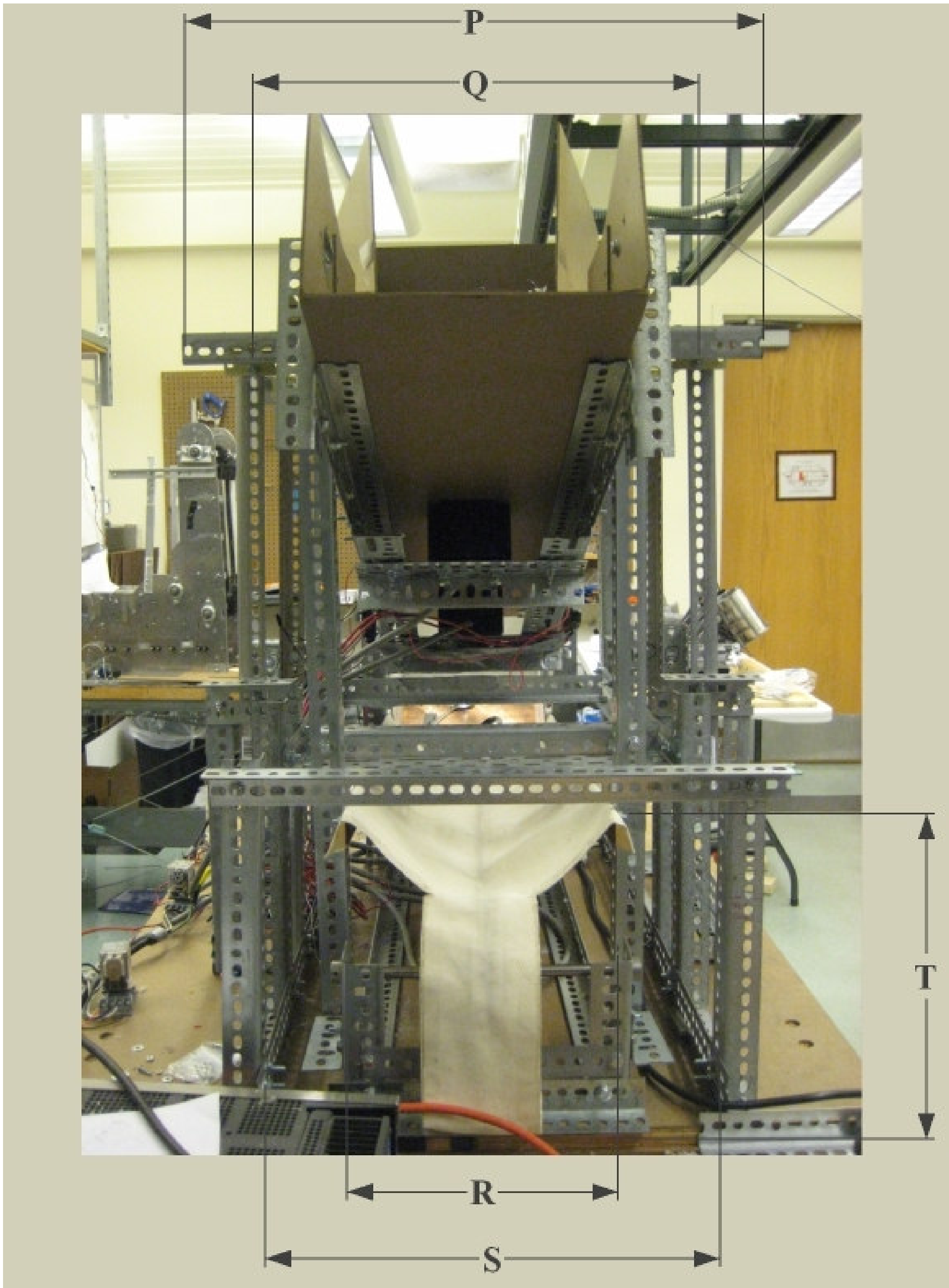
Flowchart for Singulation Process – Parallel Approach

APPENDIX – J

OVERALL DIMENSIONS OF THE EXPERIMENTAL RIG



Side View of Experimental Test Rig



Front View of Experimental Test Rig

Dimensions of support structure of the Experimental Test Rig (In Alphabetical Order)

A – Height of horizontal Angle from base – 12 ¾”

B – Height of the pulley shaft center from base – 4 $^{7}/_{8}$”

C – Height of the Angle for top end support of inclined sheet – 26 ¾”

D – Distance between front support-angles and front end of vibrating bin – 3”

E – Distance between front and back support angles of vibrating bin – 15”

F – Distance between back support-angles and back end of the vibrating bin – 6”

G – Length of the horizontal angle (base of structure) – 36”

H – Distance between the pulleys for the belt drive – 34 ½”

I – Height of the back end of the metering bin from base – 11”

J – Height of the angle supports of vibrating bin from pivot point (to support structure) to hinge (underneath base of vibrating bin) – 17 $^{7}/_{8}$”

K - Height of the Angle for bottom end support of inclined sheet – 16 ½”

L – Height of angle support to base of bin motor – 28 ½”

M – Height of Vibrating bin from base – 32 $^{3}/_{8}$”

N – Distance from the top end support of the inclined sheet to end of inclined sheet –

9 ¾”

O – Distance between base of vibrating bin and the support angle for vibrating bin (height of hinge) – 1 $^{5}/_{8}$”

P – Length of the angle attached to the base of the vibrating bin – 28”

Q – Distance between the pivot points of supports for vibrating bin – 22”

R – Distance between support angles for the inclined sheet (width of sheet, width of belt drive) – 11 ¼”

S – Distance between opposite angles for base of the structure – 18 ¼”

T – Height at which the duck cloth was fixed from the base – 11 ¼”

VITA

Venkatesh Akella

Candidate for the Degree of

Master of Science

Thesis: SILVERWARE SINGULATING SYSTEM

Major Field: Mechanical Engineering

Biographical:
Personal Data: Born in Machilipatnam, Andhra Pradesh, India, on 2nd June 1982, eldest son of Subramanyam V. Akella and Rajya Lakshmi V. Akella.

Education:
Received Bachelor of Engineering Degree from Maturi Venkata Subba Rao Engineering College, affiliated to Osmania University in June 2004. Completed the requirements for the Master of Science in Mechanical Engineering at Oklahoma State University, Stillwater, Oklahoma in December, 2008.

Experience:
Control Systems Engineer, Jacobs Engineering Inc, from March, 2008 to Current. Graduate Research Assistant, Department of Civil Engineering, OSU from Jan 2007 to Aug 2007. Graduate Teaching Assistant, Department of Mechanical and Aerospace Engineering, OSU from Aug 2004 to Jul 2005, and Aug 2006 to Apr 2007.

Professional Memberships: Member, ISA, 2008.

Name: Venkatesh Akella Date of Degree: December, 2008

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: SILVERWARE SINGULATING SYSTEM

Pages in Study: 131 Candidate for the Degree of Master of Science

Major Field: Mechanical Engineering

Scope and Method of Study:

This study investigates the singulation ('to single out') of silverware pieces in commercial dishwashing applications. An earlier version of this mechanism was developed with a stated efficiency of 40.7%. The purpose of this research was to improve on the existing design or implement a new design and develop an automated singulating rig that is capable of receiving 400 pieces of mixed randomly oriented silverware pieces, process them and pick single pieces at a rate of 30 pieces/min at higher efficiency. Major challenges associated with this study were to develop a mechanism that is capable at handling randomly oriented mixed silverware batches efficiently, to develop a reliable sensing mechanism to detect the presence of silverware at multiple locations of the test rig and to develop a mechanism that is capable of picking single pieces and delivering them from the rig. The method of study was experimental.

Findings and Conclusions:

An efficient and economical singulating mechanism has been designed and developed. A controlling method to distribute and divide large batch into smaller batches was designed and developed. A customized sensing method was designed and developed that provided reliable feedback to various actuators in the rig. Integration of all the actuators was made possible by an effective algorithm developed that allowed microprocessor to manage all rig operations. Smaller batches were further subdivided into streams of silverware, fed to the final stage, where hemi spherical NdFeB magnets were used in an effective manner to reach throughputs of 35 pieces/min at 95% efficiency.

ADVISER'S APPROVAL: Dr.Lawrence L Hoberock