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# Lunar Regolith Bagging System

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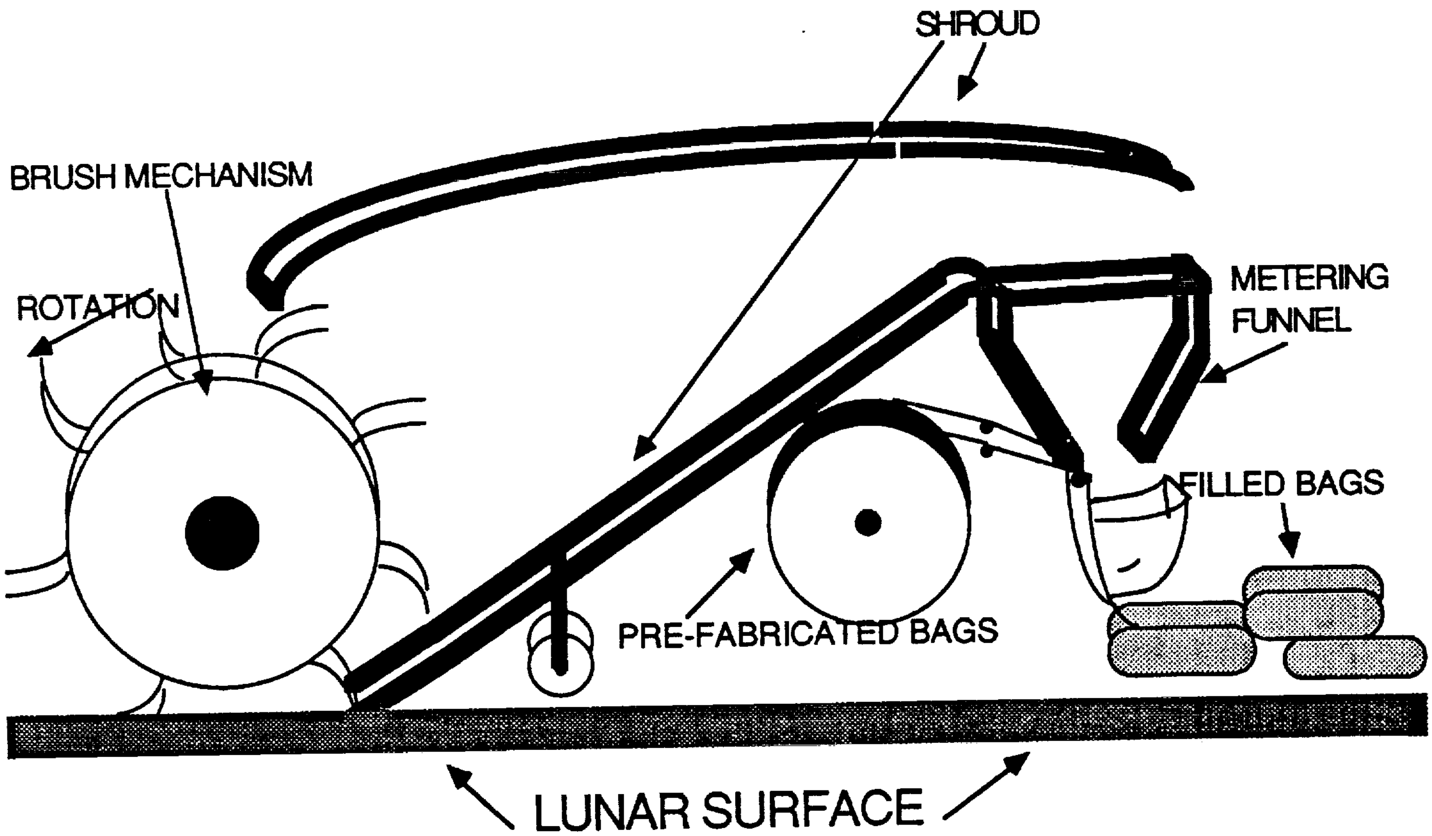
# LUNAR BAGGING SYSTEM



## SUMMARY

This paper describes a design of a lunar regolith bag and bagging system. The bags of regolith are to be used for construction applications on the lunar surface. The machine is designed to be used in conjunction with the lunar SKITTER currently under development. The bags for this system are 1 ft^3 volume and are made from a fiberglass composite weave. The machinery is constructed mostly from a Boron/Aluminum composite. The machine can fill 120 bags per hour and work for 8 hours a day. The man hours to machine hours ratio to operate the machine is .5 / 8.

## TABLE OF CONTENTS

# 1. INTRODUCTION

## 1.1 RECOGNITION OF NEED

During the continued development of systems supporting a lunar habitat, a need has arisen requiring the development of a system to utilize the lunar soil for construction applications. The need requires a system for transferring regolith into bags which can be used in the construction of various facilities. The system must be robotically controlled, use a minimal amount of energy, require minimal maintenance, have a low man-hour to machine-hour ratio, and survive the lunar environment.

## 1.2 DEFINITION OF PROBLEM

The problem can be divided into two major areas. The first area is the mechanical design of the bagging system and the second is the textile design of the bags. For the mechanical design it would be beneficial to utilize any existing technology. There is currently under development a three legged lunar SKITTER which is being designed as a transportation module for lunar needs. Therefore, a bagging system which can use this SKITTER as a base would be preferred. However, the performance limitations of the SKITTER require a system which does not exceed a given weight or geometry. The environment on the moon requires the modification of present machine materials used on earth or the development of new materials which can withstand the lunar environment. In addition, the system needs to be robotically controlled and require as little manpower as necessary. The energy requirements on the system will be very stringent due to the limited supply of power which will be available. The system must be able to bag for a certain time frame and then be recharged. For the bag design there are several problems which need to be addressed. The bag material must be able to withstand the lunar environment and provide adequate protection for the lunar habitat. The bags must be large enough so that they will provide sufficient structural support. They also must be small enough so that they can be picked up and moved by an astronaut in the event that a repair or modification to the structure is necessary.

## 1.3 BACKGROUND

The materials for both the machinery and the bags must be able to withstand the very severe lunar environment. The temperatures on the lunar surface vary from -250 to 250 degrees Fahrenheit. Since the lunar atmosphere is a vacuum the only modes of heat transfer present are conduction and radiation. Convection is not present because of the lack of air. The main mode of heating and cooling is due to the radiation. Therefore, when an object is in the sun it is very hot while if an object is in the shade it is very cold. Depending on the circumstances very large temperature gradients can be present over relatively short distances. The lack of a protective atmosphere also allows the various modes of radiation to bombard the surface of the moon. All materials must be able to withstand ultraviolet and gamma radiation. Strikes from meteorites and other space debris could also cause damage to structures on the lunar surface. Also the regolith is very abrasive. It has a density of approximately 1.2 g/cm^3 and is relatively loose for the first 10 cm of lunar surface of depth an becomes very hard and compacted at any further depth. Another problem with the soil is that it bridges extensively when metered in a conventional hopper. The bag material must be able to withstand sharp rocks or other matter which may be inadvertently loaded into the bags.

## 1.4 PERFORMANCE OBJECTIVES

The system is to be incorporated with the three legged lunar crawler. This crawler can move at speeds between 6 and 8 miles per hour. The bagging system being designed can use no more than 10 kW of energy at any one time period. The system will have an operating schedule consisting of 8 hours on-line followed by a 16 hour recharge period The ratio of man-hours to machine hours will be 1/8. Man power will be required for machine maintenance and repair including bag replacement. The machine will fill 120 bags per hour with each bag having a capacity of one cubic foot. The one cubic foot bag is necessary because the filled bags must be able to be moved by individual astronauts. The bags will be supplied on a pre-fabricated roll manufactured on earth. The machine will be 5 1/2 feet wide and 12 feet long and have a weight of 900 kG and constructed from a Boron/Aluminum composite and Graphite/Epoxy composite materials. The bags will be supplied on a pre-fabricated roll manufactured on earth and will be constructed from a glass fiber composited filament. The intended operating life for this machine is 5 years.

## 2 FINAL DESIGN OF SYSTEM

### 2.1 BAG DESIGN AND ANALYSIS

#### MATERIAL SELECTION

Glass fiber was finally selected for the design of the bags. This fiber has high strength, a tenacity of 6.3 to 6.9 grams per denier. Elongation is only 3 to 4 percent, but elastic recovery is 100 percent. The fiber has outstanding dimensional stability, and it can absorb extreme stress without permanent deformation. In general, glass fiber does not have good abrasion properties, but the purpose of the design is to use the bags only once to store regolith for a period of time, taking abrasion requirements to a minimum. Density is 2.49 grams per cubic centimeter, which may sound too dense for general apparel use but quite satisfactory for the lunar habitat. The fibers do not absorb measurable amounts of moisture, and they have good resistance to creasing and wrinkling. They are smooth, even, transparent, and circular in cross section.

Glass fiber will not burn; however, it will soften at about 815∞C (1500∞F), and strength begins to decline at temperatures above 315∞C (600∞F). It exhibits excellent resistance to age, sunlight and weather. On the moon it will have an excellent resistance to UV and g radiation. A summary of bag materials can be seen in Table 1.

#### FABRIC CONSTRUCTION

Glass fiber will be woven to form the fabric. Plain weaves, consisting of yarns interlaced in an alternating pattern, one over and one under every other yarn, provide the most fabric stability and durability compared to other construction methods.

The bags may be formed by either bonding or sewing . Bonding involves joining the fabric together using a polymer based resin. Because polymeric materials degrade with exposure to

Gamma radiation, bonding was eliminated as a consideration. Sewing variables include yarn type , stitch type and stitch density. Since polymeric materials cannot be used, glass yarns were chosen. A stitch density of 40 stitches per inch was specified .

The specific type of plain weave selected for the design of the bags was provided by Clark-Schwebel Fiber Glass Corporation. Some of the characteristics of the fabric include the following:

Thread count: 44x32 ends/inch
Weight: 6 ounces/yard$^2$
Thickness: 0.0068 inches
Breaking Strength: 250x200 Lbs.F/inch
Warp Yarn: ECG 75-1/0
Filling Yarn: ECG 75-1/0

ECG 75-1/0 is the fiber glass yarn nomenclature which means the following:

E- Characterizes the glass composition.

| Composition | E Glass |
|---|---|
| Silicon dioxide | 52-56% |
| Calcium oxide | 16-25% |
| Aluminum oxide | 12-16% |
| Boron oxide | 8-13% |
| Sodium and potassium oxide | 0-1% |
| Magnesium oxide | 0-6% |

C- Indicates the yarn is composed of continuous filament.
G- Denotes the individual filament diameter: 0.00036 in.
75- Represents 7,500 yards/pound.
1- Represents the original number of twisted strands.
0- Represents the number of these strands plied together.

## 2.2 MACHINERY DESIGN AND ANALYSIS

A schematic of the machine is shown in Figures 1,2. The design consists of many components which in themselves had to be designed and researched. A list and analysis of the components is below.

The Machine operation is summarized in Flowcharts 1 thru 3

I. Sweeper mechanism
II. Trajectory analysis of soil
III. Dimensions of the machine
IV. Construction of the shroud
V. Funnel system
VI. Bag rolls and support system
VII. Bag opening method
VIII. Full bag detection system
IX. Bag cutter
X Bag Sealing
XI. Clutch / brake assembly for bag drop off
XII. Materials

### I. SWEEPER MECHANISM:

The sweeper design is a modification of an existing sweeper. The modification is done to a model LEL4800 sweeper which is manufactured by the *Sweepster Jenkins Equipment Company INC.* This design was selected among several other contenders for several reasons. As a model for this system we thought of using a city street sweeper type of brush mechanism. However, there are several problems with such a design. First of all, street sweepers are very large and very heavy. The motors required to drive this system are very powerful and require a lot of horsepower. The maximum amount of power that our entire system can use is 10 Kw which is 13.3 horsepower. The drive systems on street sweepers are around 130 horsepower ( 97.7 kW )which is far too great for our applications. Furthermore, the brushes are actually driven by hydraulic pumps which are driven by the drive engines for the vehicle. A hydraulic system would not be a good choice for lunar application because problems with freezing or boiling of the hydraulic fluid may be encountered.

The basic brush design is as follows. The brush width is 5 ft ( 1.6m ) and has a brush diameter of 2 ft ( .6m ). The brush material will be modified from a polypropylene plastic to a aluminum/boron fiber composite material. The mass of the brush will be 6.21 lbm. The maximum rated RPM for this brush is 150 RPM. The brush drive system will consist of a 5 horsepower ( 3.76 Kw ) motor with a 11 to 1 gear reduction system. The brush manufactured by *Sweepster* has a 5 horsepower Briggs & Stratton gasoline engine but an aspirated combustion engine will not work on the lunar surface without its own air supply. Although not lunar rated we did research an electric D.C. motor that did deliver 5 horsepower ( 3.76 Kw ). The *Reliance Electric Co.* model B1811ATZ produces 5 horsepower at 1750 RPM. The mass of this motor is 4.97 lbm. The final drive will be from #40 chain and sprocket made from Graphite/Epoxy composite material. The expected weight of the entire system will be approximately 60 lbs ( 18.26 N ) **on the lunar surface.** The calculations relating motor torque and brush speed are listed in Table 3 and Graphs 1 and 2. These calculations assume a coefficient of static friction between the brush material and the soil to be about 0.8.

## II. THROWN SOIL TRAJECTORY ANALYSIS

Because of the fact that there is no air resistance in lunar applications, the trajectory of the soil which is thrown up by the brush can be modeled very accurately. The length dimension of the machine is dependent upon this soil trajectory. An analysis of the soil trajectory as it relates to brush RPM is shown in Table 4. The analysis is done assuming a 30 degree angle of incidence between the lunar surface and the thrown soil. Due to the constraints of the machine in order for our design to work to soil must be able to be lifted to a height of 5.25 ft (1.6 m ) from the lunar surface. As shown in Table X.X for a brush rotation of 150 RPM the soil would have to be thrown horizontally 18.37 ft ( 5.6 m ) to reach a maximum vertical height of 5.25ft (1.6 m ). If this data is accurate this means that or machine would have to be at least 18.37 ft ( 5.6 m ) long. However, to maintain stability of the crawler and the bagging system it would be beneficial to make the system as compact as possible. Therefore, we propose to coat the inside of the shroud with Teflon which has a very low coefficient of friction. The thrown soil can then be deflected by the shroud to get it up to the required height. Therefore, the length dimension of the machine will be 9.84 ft ( 3 m ) long.

## III. DIMENSIONS OF MACHINE

The dimensions of the machine were governed primarily by the geometric constraints imposed by the geometry of the SKITTER. Since there is no published data on the SKITTER we had to make some assumptions about its operation. We assumed that it is possible for the SKITTER to reach the minimum height above the ground of two meters during normal walking operations. Therefore, our machine design is 6.56 ft ( 2 m ) tall. The width of the machine was governed by the width of the brush mechanism up front. In order to take full advantage of the entire five feet of sweep width for the brush the machine will be 5 feet ( 1.6 m ) wide. The length of the machine was governed by the trajectory of the soil thrown up from the ground. The optimum length of the machine would be 18.37 ft ( 5.6 ) meters as explained in section II above. However, the modifications to the shroud warrant a machine length of 11.84 ft ( 4 m ). Detailed drawings of the machine and its components are shown in Figures 1 thru 2.

## IV. CONSTRUCTION OF THE SHROUD

The shroud is designed to fulfill two main objectives: protection of operating machinery and control of the soil trajectory.

With regard to protection the shroud acts as a shielding device for such equipment as the pre-fabricated bag roll, cutting device, clutch/drop mechanism, bag opening device, bag full sensing device, and motor/gear assembly for the brush motor. The shroud will protect these components from large flying objects which could cause damage as well as keep the amount of contamination by the lunar soil to a minimum.

The primary role of the shroud is to act a a guide duct for the thrown up regolith. As stated earlier in order to compact the design the shroud will be designed to guide the soil up to the top of the funnel. The inside of the shroud will be coated with Teflon to reduce to coefficient of friction between to lunar soil and shroud material.

## V. FUNNEL SYSTEM

The design of the funnel is very important to the success of the machine. The funnel had to be designed in order to hold a capacity of 10 bags of soil and be resistant to bridging. In order to prevent bridging it was required that the walls of the funnel be at a greater than 60 degree angle with respect to horizontal. An analysis of funnel height with respect to funnel top diameter and bottom diameter was performed to find the optimum dimensions of the funnel for the required volume capacity. The results of this analysis can be found in Table 5. The optimum funnel design will have a height of 3.28 ft ( 1.0 m ), a top diameter of 3.67 ft ( 1.12 m ) and a bottom diameter of .98 ft ( .3 ) meters.

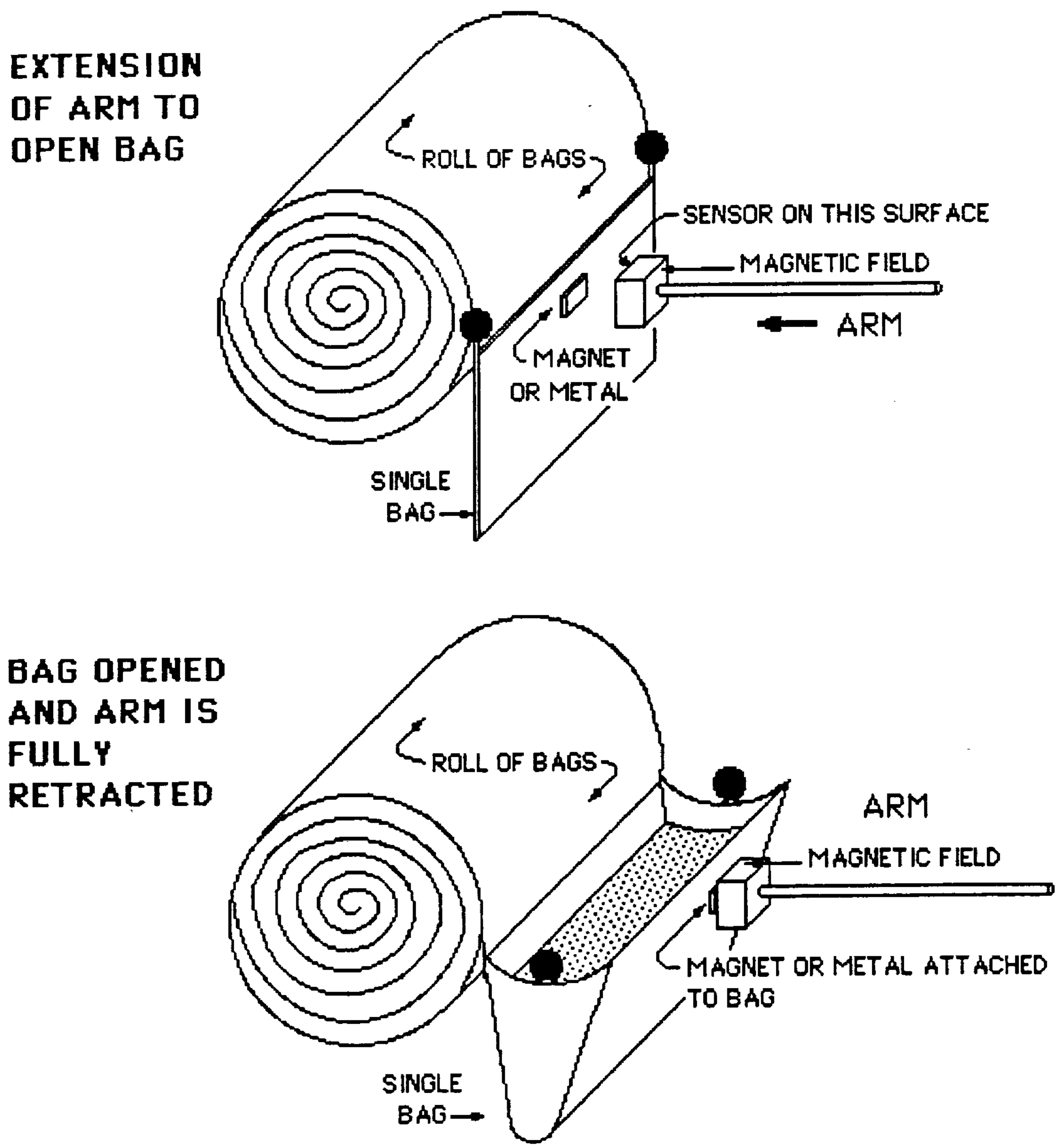
## VI. BAG ROLL SUPPORT SYSTEM

The bags for this process will come off a pre-fabricated roll. Each roll will have 975 bags on it. A full roll will weigh 159.9 N on the lunar surface and have a diameter of 3.18 ft (0.97 m). This allows for a 6 inch ( .15 m) clearance between the bottom of a full roll of bags and the lunar surface. The center of the roll will be a hollow shaft made out of a Boron - 6061 Aluminum composite. On both sides of the roll there will be a support beam designed to hold up the roll of bags. A diagram of the system is shown in Figure 3. The Figure shows that the shaft will be designed to slide into the slots located at the bottom of the support members. This design allows for the easy loading of fresh rolls of pre-fabricated bags by a robot. As shown the slots on the support members have electronic check valves to insure that the bag rolls do not come loose during machine operation or transportation. An analysis of the size of the shaft needed for the bag rolls is provided in Tables 6 and 7. The shaft was designed using the maximum shear stress theory.

## VII. BAG OPENING METHOD

Because the bags are coming off a roll there needs to be some way to insure that the bags stay open while they are being filled. This need will be satisfied using magnetics. Each pre-fabricated bag will have a small piece of metal near the opening on the outer side of the bag. As an empty bag is placed into position a small arm with an electromagnet will move to the opening of the bag. When the electromagnet is charged it will attract the metal strip fabricated into the bag. With the aid of a small servo-motor the electromagnetic arm will then retract which will draw one end of the bag so that the bag will be in the full open position. The motor used for this application is modelled after a *Compumotor* model KSX-260. This motor is rated at .42 horsepower ( .315 kW ) and has a peak torque of 56.25 lb-in ( 6.36 Nm ). In addition, when the end of the bag is attached to the electromagnetic arm it will compress a switch which will inform the rest of the system that a bag is in place and that it is ready to be filled. After the bag has been filled with soil, the electromagnet deenergizes which allows the bag to close. The bag is then cut and dropped from the roll. The process for opening the bag is then repeated. A diagram of this procedure is shown on the following page Figure 3.

FIGURE 3, BAG OPENING METHOD



## VIII. FULL BAG DETECTION SYSTEM

A system must be employed to regulate the amount of regolith that is supplied to each bag. This is very important since if a bag were to be filled too much the sealing method would not work effectively. Also if the bag were not filled enough it may cause problems when the bag is applied to the construction applications. The system to monitor volume in our design uses strain gauges and a microprocessor.

The strain gauges are attached to the magnetic arm that holds the bags open. A diagram is shown in Figure 4 . The strain gauges measure the deflection in the arm and send the information to the microprocessor for analysis. When the system detects a deflection of . a signal is sent to the magnetic arm system to release the bag. This deflection indicates that the bag is full and that any further regolith addition would jeopardize the bag closure seal This system is modelled using components from *Motorolla* MC 68HC 11 A8 micro-controller. An analysis of the signal processing and deflection is shown in Tables 8 and 9 as well as a listing of the program.

## IX. BAG CUTTER

Since the bags are on a continuous pre-fabricated roll there must be some way to separate the full bags from the empty bags. Since the bags are made from a glass reinforced composite, it will not be very easy to cut the material. Therefore, the cutting mechanism will consist of a double edged diamond tipped cutting blade. The blade will be mounted on a rod like mechanism so it can slide back and forth. The motion of the blade will be accomplished by connecting a servo-motor ( *Compumotor* model KSX-260 ) to the mechanism analogous to the system used by a dot matrix line printer. After the the arm that holds the bag open releases the bag, a signal will be sent to the blade mechanism instructing it to make a cutting pass which will release the full bag from the rest of the roll. A new empty bag is then fed into position and the process repeats as required.

# X. BAG SEALING

For this system the bags will be sealed by using a draw string method like that used on a garbage bag or a laundry bag. The draw strings will be fabricated into the bags. The draw strings will be composed of Kelvar. There will be no tying or twisting of the strings in order to seal them. The draw strings will have raised barbs on them which permit them to move in one direction through the eyelets on the bag. The bag eyelets will be reinforced so that the barbs cannot move back into the bags which would be detrimental to the seal of the bags. The draw strings will actually be in the form of a continuous loop and will have two hard boron/aluminum composite balls on them. The loop is present because it makes it easier for the recovery team to recover the filled bags. A long pole or other device can be used to simply scoop-up the loop in the draw strings and carry them back to base. The balls are needed in order to facilitate the closing of the bag as it drops of the machine. What occurs is that after the bag is full and released from the electromagnet, the balls slide into slots on a clutch and held there. After the bag is released its own weight causes it to drop but the draw strings are held in one place. Therefore, the draw strings are in effect pulled out and the bag is sealed. The clutch then releases the balls and the full bag is discarded to the lunar surface.

# XI. CLUTCH / BRAKE ASSEMBLY FOR BAG DROP-OFF

In order to insure an efficient and smooth way to drop off the filled bags a clutch system is used. To reduce the risk of bags being damaged or ruptured they must be laid as gently as possible on the lunar surface. After a bag has been filled and the electromagnet holding the bag has been deenergized the bag falls to the ground closing the draw strings which are held in the clutch plate assembly. At this point the brake holding the clutch stationary is engaged. After a half second delay, the brake releases and the clutch lowers the bag gently to the ground. A table showing the torque resistance in the clutch related to position is shown in Table 10. The brake is reapplied after the clutch rotates 120 degrees where a new, empty bag is then positioned. The clutch and brake assembly used in this design is patterned after a combination of a model 602s0350 brake and a model L2-1-313A clutch manufactured by *Hilliard corp.*.

## XII. MATERIALS

The Materials for the structure of this machine had several different constraints. These materials had to be strong, lightweight, machinable, Have good thermal properties, and be resistant to radiational degradation. The machine components are made from two composite materials. The shroud of the machine is made of a Boron/Aluminum composite. This material hs a modulus of 32 msi, a thermal conductivity of approximately 0, a yield strength of 210 ksi and is currently being used on the Space Shuttle on various component parts. The other components are made from a Graphite/Epoxy composite. This material has a modulus of 70 msi, a thermal conductivity of approximately 0, and a yield strength of 360 ksi. This composite is also being currently on the Space Shuttle in such components as the deployable robot satellite access arm. Since these materials have already shown competence in orbital applications we are hopeful that they will give us acceptable performance on the lunar surface.

The maximum weight of the entire machine is summarized below:

| | |
|---|---|
| Sweeper mechanism | 5.08 Kg |
| Full roll of bags and shaft | 79.75 Kg |
| Full hopper | 339.80 Kg |
| Servo motors | 20.10 Kg |
| Controllers | 15.00Kg |
| Support structure | 250.00 Kg |
| Total | 709.73 Kg |

## PERFORMANCE

The overall performance of the system is summarized in the following table.

| | |
|---|---|
| MAXIMUM OPERATING TIME PER CHARGE | 8 Hours |
| RECHARGE TIME | 16 Hours |
| MAN HOURS/MACHINE HOURS | .5/8 |
| ENERGY CONSUMPTION | 5.705kW |
| MAXIMUM NUMBER OF BAGS PER ROLL | 975 |
| BAG SIZE | 1 ft^3 |
| PHYSICAL OPERATING LIMITS ROLL | 5 degrees |
| PITCH | 5 degrees |
| NET WEIGHT | 709.73 Kg |
| MACHINE LIFE | 5 Years |

An analysis of the structure is shown in Figure 5.

## CONCLUSIONS AND RECOMMENDATIONS

The overall design of this machine as well as the individual systems which make up this design have been analyzed in as much detail as possible regarding the time constraints of the class. The system we designed is very feasible and is capable of performing as planned

Several different systems were contemplated for this design. The alternates are discussed in detail in the appendix. The design we chose to implement is successful in meeting or exceeding the performance constraints outlined in the introduction. However, some of the parts used for this design were used strictly from earth sources. For example, the motors referenced for this design would have to modified for lunar applications. Therefore, these components would have to be developed before the system could be implemented.

Finally, a prototype could be constructed on earth and tested using regolith simulates.

# 4.APPENDIX

# 4.1 DESIGN SELECTION CRITERIA

## 4.1-1 BAG MATERIAL CONSIDERATIONS

### MATERIAL SELECTION

The material selection process was the most important factor considered in the design of the bag. Many alternatives were taken into account, but only a small number of them could fulfil the requirements and constraints of the lunar habitat. Some fibers with their respective characteristics are shown in the Fiber Table (table 1).

Of the 27 materials considered, the first choice was polyester. Polyester was chosen for its superior resistance to UV and its low density. Polyester's strength is more than adequate to withstand the bagging stresses. The Tg of polyester is 69∞C, which would be lowered by copolymerization with a siloxy group. The polyester/siloxy copolymer was discarded when the level of Gamma radiation was found to be to great for any organic polymer.

Next, since organic materials were eliminated, the search was focused on inorganic materials. The inorganic materials under consideration were silicon carbide, boron nitride, glass, carbon fiber and asbestos. Of these, boron nitride, carbon fiber and glass were given closer scrutiny. Boron nitride was eliminated because of the difficulty to get a high quality fabric that would not degrade on the moon. Carbon fibers were acceptable, but its extremely high modulus was deemed a disadvantage for flexibility. Finally, glass fiber was chosen because of its moderately high modulus, good radiation resistance, and its ability to meet the criteria already mentioned. The only disadvantage of glass when compared to carbon fiber is that the latter one has a lower density.

FIBER TABLE

| FIBER | DENSITY (g/cc) | BREAKING STRENGTH | | MODULUS OF ELASTICITY | | Tg (C) | Tm (C) | UV | γ |
|---|---|---|---|---|---|---|---|---|---|
| | | g/den | psi*10^3 | g/den | psi*10^6 | | | | |
| Polyethylene, exptl. drawn | 0.92 | 85+ | 1000+ | 1230 | 145 | -125* | 132 | P | VP |
| Polyethylene, spectra 2000 | 0.97-0.98 | 35-60+ | 437-749+ | 2000 | 25 | -125* | 115 | P | VP |
| Polyaramide, Kevlar 49 | 1.45 | 26 | 480 | 1080 | 20 | | 500 | VP | VP |
| Polyvinyl alcohol (allied) | 1.33-1.34 | 20+ | 342 | 600-800 | 10.3-13.7 | 85 | 250 | VG | VP |
| Polyaramide, Kevlar 29 | 1.44 | 26 | 480 | 1540 | 10 | 230 | 255 | VP | VP |
| Nylon 6, freeze spun | 1.14 | 15 | 220 | 36 | 0.52 | | 216 | F | VP |
| Silicon Carbide | 3.30-3.42 | 10.4 | 450 | 1440 | 62 | N/A | N/A | G | G |
| Boron Nitride | 2.38 | 18(10-25) | 540(300-750) | 1840 | 56 | N/A | N/A | G | G |
| Polyester, H.T. | 1.38 | 9.5 | 170 | 45-90 | 0.8-1.6 | 69 | 250 | G | VP |
| **GLASS** | **2.49** | **21(6-30)** | **660(190-960)** | **390** | **12.4** | | **>1090** | **VG** | **VG** |
| Nylon, H.T. | 1.13-1.14 | 9.5 | 140 | 20-60 | 0.3-0.9 | 230 | 255 | F | VP |
| Polypropylene | 0.90-0.91 | 9 | 100 | 20-60 | 0.2-0.7 | -12 | 170 | P | VP |
| Poly (vinyl alcohol) | 1.26-1.30 | 3.8-9 | 60-150 | 35-155 | 0.6-2.6 | 85 | 250 | F | VP |
| Flax (linen) | 1.5 | 7.7 | 150 | 250 | 4.8 | N/A | N/A | P | VP |
| Rayon | 1.5 | 7 | 130 | 13-50 | 0.25-0.96 | 150 | 170 | P | VP |
| Ramie | 1.55 | 6.7 | 138 | 150 | 3 | N/A | N/A | P | VP |
| Hemp | 1.48 | 6.2 | 120 | 180 | 3.4 | N/A | N/A | P | VP |
| Cotton | 1.55 | 5.8 | 115 | 50 | 1 | N/A | N/A | P | VP |
| Polyethylene, H.O. | 0.95-0.96 | 3.5-7 | 43-86 | 20-50 | 0.24-0.61 | | 130 | P | VP |
| Silk | 1.25 | 5 | 80 | 22 | 0.35 | N/A | N/A | P | VP |
| Modacrylic | 1.25-1.37 | 4.2 | 70 | 3.8-42 | 0.06-0.74 | N/A | N/A | P | VP |
| Acrylic | 1.16-1.18 | 4 | 60 | 5-10.4 | 0.07-0.16 | N/A | 317 | P | VP |
| Polyethylene, L.O. | 0.92 | 1.0-3.0 | 12.5-35 | 30-40 | 0.5-0.67 | -125 | 140 | P | VP |
| Wool | 1.32 | 1.7 | 29 | 3.6 | 0.061 | N/A | 120 | P | VP |
| Acetate | 1.32 | 1.2-1.4 | 20-24 | 3.5-5.5 | 0.05-0.09 | | N/A | P | VP |
| Teflon | 2.1 | 0.5-1.6 | 13-43 | 1.0-8.8 | 0.027-0.24 | | 260 | G | VP |
| Carbon(fiber) | 1.7-1.96 | 12.5-20 | 260-500 | 1120-3580 | 28-78 | N/A | N/A | G | G |

TABLE 1

## FABRIC CONSTRUCTION

In selecting a fabric for industrial applications, a number of design parameters may be considered. These are broken down into four basic variables: yarn weight, thread count, weave pattern and fabric finish. Yarn weight combined with thread count, that is the number of warp ends and filling picks per inch, determine the strength, weight and thickness of the fabric.

Some of the alternatives for fabric construction were wovens, knits, and nonwovens. Circular weaving was considered for organic materials, but after deciding to go with inorganic materials, the method was discarded for its difficulty of manufacture. Knitting, commonly defined as forming a fabric by means of interlooping yarns, was also discarded because of the poor abrasion properties and the high elongation it has. Nonwovens were discarded because the textile structure is produced by bonding or interlocking of fibers, accomplished by mechanical, chemical, thermal, or solvent means that would be extremely affected by the lunar habitat. Finally, plain weave, consisting of yarns interlaced in an alternating pattern, one over and one under every other yarn, was considered for the construction of the fabric using an inorganic material.

## 4.1-2 BAG DESIGN AND CONSTRAINTS

The design of the regolith bag must withstand exposure to the conditions on the moon as previously described. The design must be evaluated by specific physical properties, mechanical properties, thermal properties, chemical properties and fabrication properties.

Physical properties of the bag material which must be considered are density, melting point, reflectivity, porosity and dimensional stability. Density is important for evaluating transportation costs. The bag should be of minimum mass while still meeting the criteria of the design. Also, the weight of the bags under the SKITTER must be kept to a minimum.

The melting point of the bag material must not be within the temperatures which exist on the moon since the material would lose its composition and fail. The glass transition temperature, which is related to the melting point of polymers, must be below the lowest temperature on the moon since the polymer must not crystallize and fracture if the temperature were to fall below the glass transition.

To protect against UV radiation the bag must reflect the incident UV range of the lunar spectrum to prevent degradation of organic materials, if chosen. This may be accomplished by the material itself or by the addition of a reflective coating on the bag. Of course, any coating must also satisfy the criteria of the bag itself and be compatible with the bag material.

The bag must also be dimensionally stable and have appropriate porosity. The bag cannot change shape drastically and still be filled and sealed properly by the machine. The bag should be of a porosity or space between fibers so that the regolith particles may not escape.

Mechanical properties which must be considered are modulus of elasticity in tension, yield strength in tension, ultimate strength in tension, creep and abrasion. The modulus of elasticity must be low enough so that the bag is not too stiff and brittle. The bag must conform well to other bags while stacked on the structure to reduce the chance of sliding past each other. In this respect, the coefficient of friction is also important. Of course, the yield strength and the ultimate strength of the fabric must be enough to withstand the loading and distribution operations. The material also must not creep drastically while on the structure, but moderate creep will actually improve the stability of the stacked bags by conforming with each other. Another important characteristic is abrasion resistance which must be great enough to withstand any sharp regolith or rubbing during the filling and distribution operations.

Thermal properties which must be considered are coefficient of expansion and emissivity. The coefficient of expansion is most important if coatings are used because the fabric and coatings must expand and contract to the same degree. The emissivity is the ability of the material to radiate heat. This property and absorption must be of a level so that energy can be dissipated to prevent any thermal damage to the material.

Finally, the chemical properties to be considered are ultraviolet and gamma radiation degradation and thermal stability. UV and g degradation are the most critical properties to be considered for the material, since failure to withstand these would result in catastrophic structural failure of the bags with time. Thermal stability has been addressed with respect to glass transition, melting point, creep, emissivity and absorption.

### 4.1-3 BAG MECHANICS

The mechanical requirements of the bags were divided into four categories:

1.) Bag opening methods
2.) Bag sealing methods
3.) Bag full sensing methods
4.) Bag cutting methods

For each of these areas several different methods for achieving the desired result were explored. The results are summarized below.

1) Bag opening methods:

A) Construct the bags with a spring at the opening to hold the bags open while filling.
B) A mechanical device to pull the bags open.
C) A gas charge to force the bags open
D) A mechanical device to push the bags open
E) Construct the bags with a small piece of metal at the opening which can be magnetically pulled open by an actuator.
F) Electrostatic force.
G) Use inertia to whip the bags open.
F) Use a chemical reaction.

Bag opening methods:

We elected to implement the electromagnetic system to hold the bags open while filling.

Bag sealing method:

We elected to implement the draw string type closure method.

Bag full sensing methods:

We elected to implement the strain gage/beam deflection method.

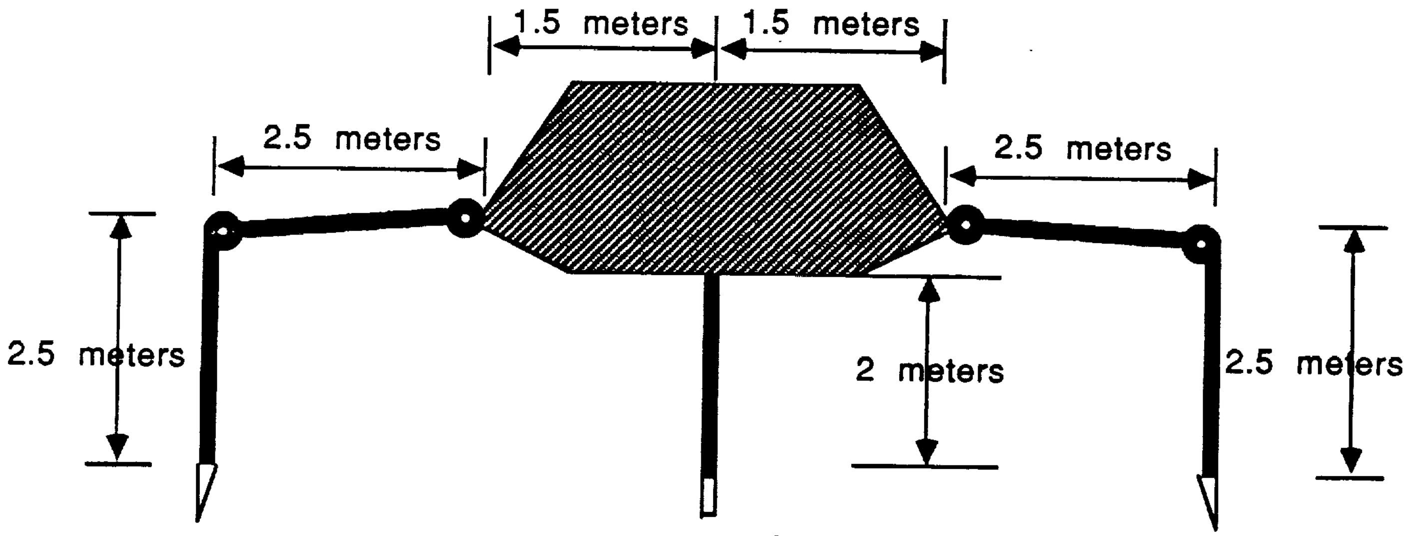
Bag cutting method:

We elected to implement the diamond tipped servo cutter method.

### 4.1-4 MACHINERY DESIGN AND CONSTRAINTS

The overall design of the system had to remain within several constraints. First of all, the overall size of the machine was a factor. Figure X.X shows a schematic of the dimensions of the lunar SKITTER. The SKITTER is shown in its maximum deployed position. As can be seen the maximum allowable height for the machine is 6.56 ft ( 2 m ) while the maximum width is 26.25 ft ( 8 m ). However, it is desirable to keep the bagging system under the body of the SKITTER as much as possible. Therefore the Maximum operating width is about 11.84 ft ( 4 m ). The maximum weight for the entire system is 1 metric ton ( 1000 Kg. ) on the lunar surface. The entire system can use no more than 10 Kw of energy. The design must be able to withstand temperature fluctuations from 250 degrees Fahrenheit to -250 degrees Fahrenheit. Bearings and moving parts must be protected from contamination by the lunar soil and other environmental contaminants. Structural materials must also be resistant to degradation from various forms of radiation.

## SKITTER SCHEMATIC




For the machinery four preliminary designs were explored. Sketches of the designs are shown in Figures X.X thru X.X. The analysis of the advantages and disadvantages of each design is described for each figure.

## Design #1

Advantages:

1. Storage system in the hopper
2. Continuous feed of filled bags that can be easily transported to the habitat for construction.
3. Equal and opposite forces in the brush and scoop: This forms a self-contained system that has no static effects on the crawler.
4. Bags can remain attached in sets of three which facilitates easier transportation of bags.

Disadvantages:

1. Complicated process which includes hydraulic lifting.
2. Requires heat sealing or sewing of two separate layers of cloth; a very complicated process.
3. Requires large amounts of energy.
4. Bulky system that requires a large amount of space under the crawler. This would cause it to be unstable due to the dynamics of the crawler movement.
5. The conveyers account for a lot of wasted energy
6. Inefficient use of available space.
7. Difficult maintenance.

## Design #2

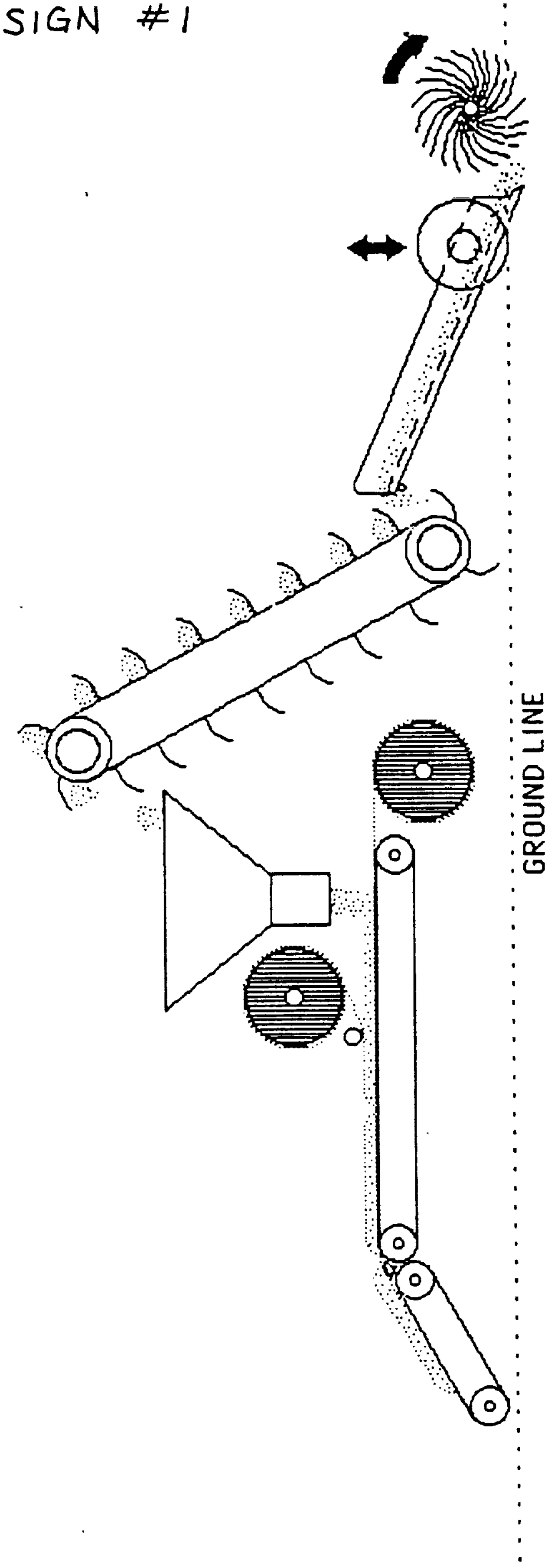
Advantages:

1. Less machinery
2. Simple process.
3. Pre-fabricated bags.
4. Free standing nature creates inherent stability.

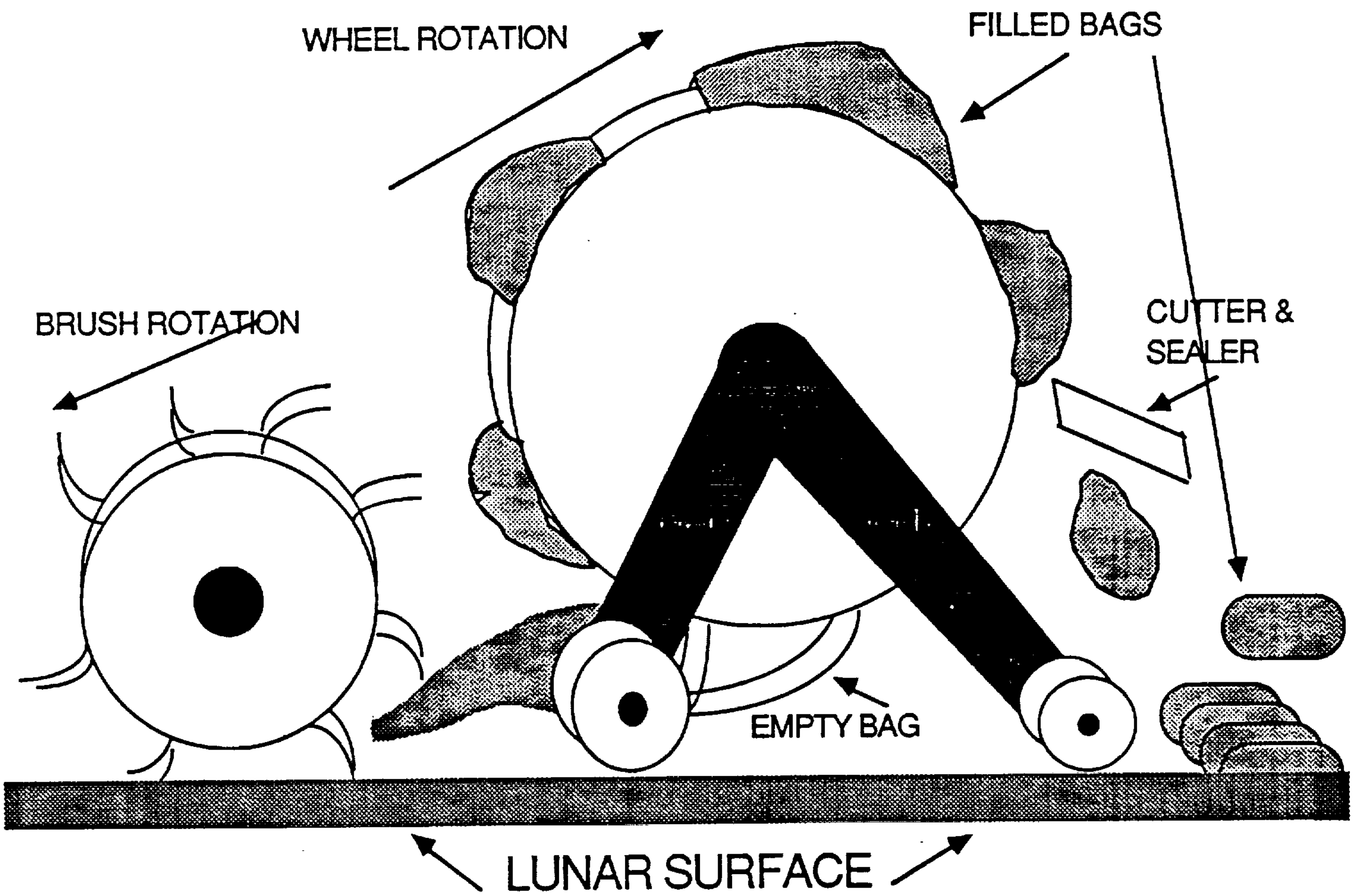
Disadvantages:

1. Uses too much energy.
2. Requires the lifting of loaded bags.
3. Loaded bags are left scattered on lunar surface.
4. Inefficient process for filling bags.
5. Uncontrolled regolith which is thrown-up may contaminate mechanical linkages.
6. Requires constant movement of the crawler.
7. No volumetric metering of bag capacities.

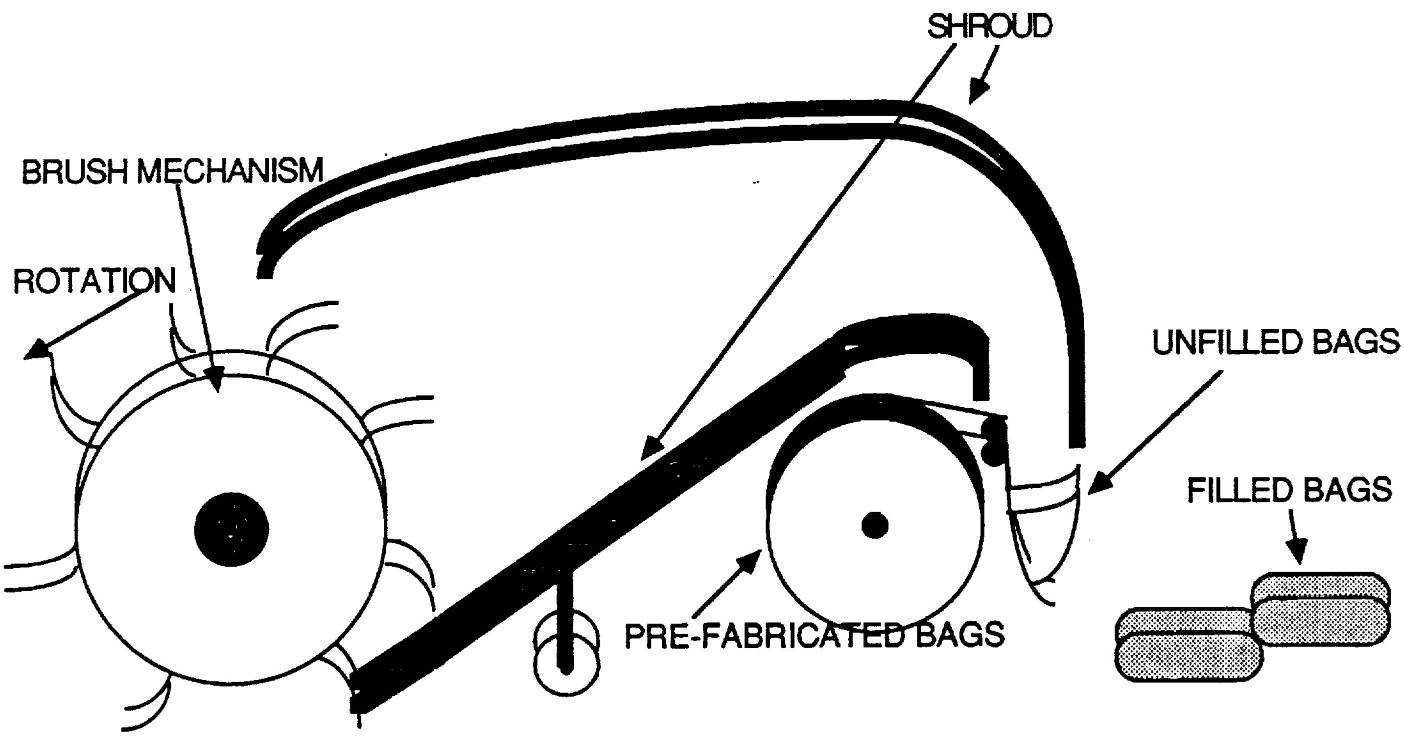
DESIGN #1



DESIGN #2 LUNAR BAGGING SYSTEM



## Design #3



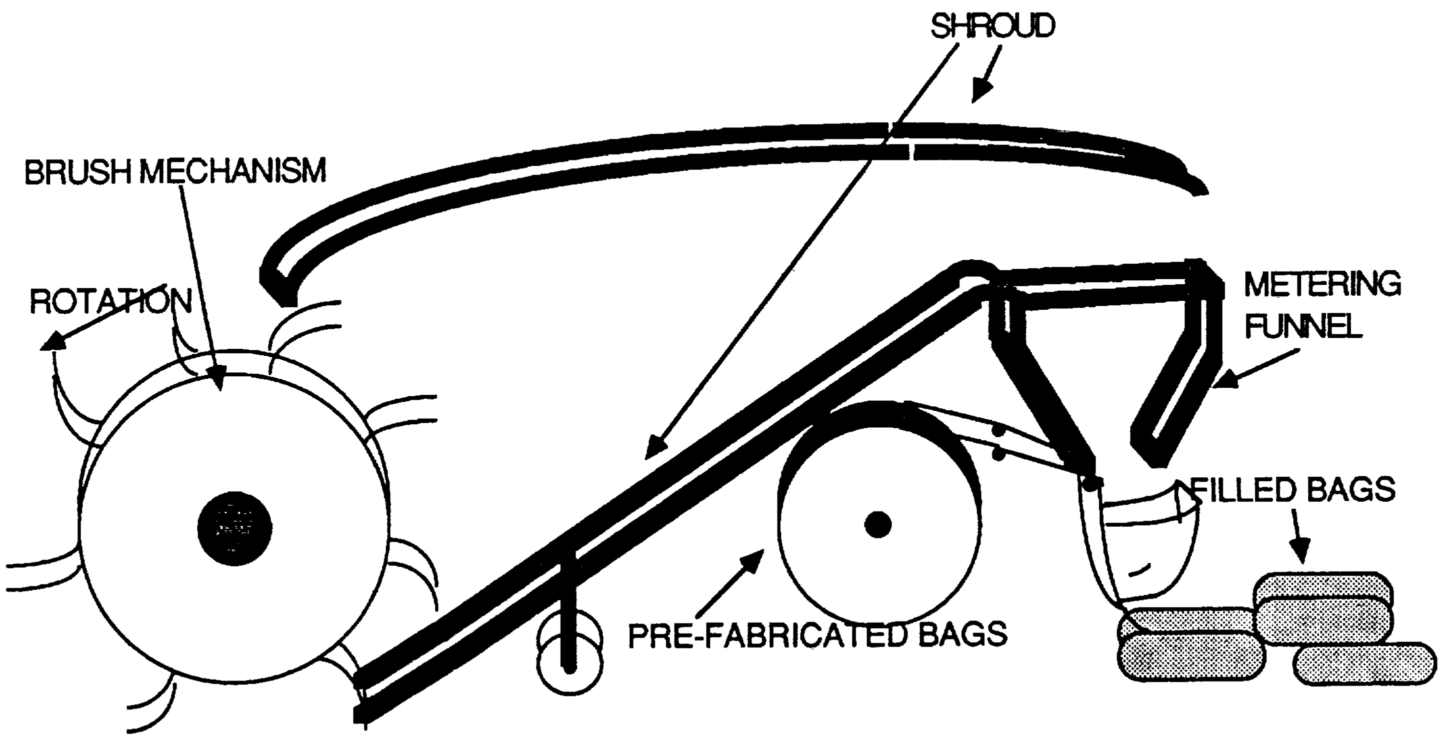

Advantages:

1. Moves along the surface and maintains the proper clearance for brush and tray.
2. Bags are easier to handle and fill when they are on a pre-fabricated roll.
3. The shroud catches regolith and directs it towards the bags
4. Compact design.
5. Equal and opposite forces between the brush and tray.

Disadvantages:

1. No metering device for regolith.
2. Must continuously move to fill the bag.
3. Bags are dropped randomly.
4. Hard to seal bags in this position.
5. Collection tray is long and does not prevent regolith from sliding down the wrong way.

## Design #4




Advantages:

1. Volumetric metering of bag capacities.
2. Does not require constant movement of crawler.
3. Storage capacity in hopper.
4. Shroud provides good control of regolith.
5. The design minimizes power consumption.
6. The bag undergoes a short drop from the collector to the ground.
7. Provides for a cluster of filled bags in a localized area.
8. Moving mechanical parts shielded from flying debris.
9. Pre-fabricated bags.
10. Efficient use of limited space.

Disadvantages:

1. Added weight due to storage.
2. Bridging problems possible in funnel.
3. Control of funnel operations may be difficult.

After weighing the advantages and disadvantages of each design we elected to implement the design shown in Figure 4. This design consists of a rotating brush, protective shroud, Metering funnel, Prefabricated bags on a roll with built in draw strings, a cutter to cut filled bags from the roll, a clutch mechanism to pull the draw strings closed, and a magnetic control arm to hold the bags open while filling.

# DESIGN MATRIX

Rating Scale: 1 worst-----4 best

| Design Factors | Design #1 | Design #2 | Design #3 | Design #4 |
|---|---|---|---|---|
| Energy consumption | 1 | 2 | 4 | 3 |
| Duration of operating schedule | 1 | 2 | 4 | 3 |
| Man/Machine Hours | 1 | 2 | 3 | 4 |
| Bagging capacity | 3 | 1 | 2 | 4 |
| Static/dynamic stability | 1 | 4 | 2 | 3 |
| Weight of machine | 1 | 2 | 4 | 3 |
| Simplicity of design | 1 | 4 | 2 | 3 |
| Durability | 1 | 2 | 4 | 3 |
| Simplicity of process | 1 | 4 | 2 | 3 |
| Amout of new part design required | 2 | 1 | 3 | 4 |
| Transportability | 1 | 4 | 3 | 3 |
| Production rate | 3 | 1 | 2 | 4 |
| Size Constraints | 1 | 1 | 3 | 3 |
| Min. movement of crawler | 3 | 1 | 2 | 4 |
| Localized area of bag drop | 3 | 1 | 2 | 4 |
| | 24 | 32 | 42 | 52 |

# MATRIX

| [illegible] | Boron Nitride | Glass | Carbon Fiber |
|---|---|---|---|
| [illegible] | 2 | [illegible] | — |
| [illegible] | 4 | 5 | [illegible] |
| [illegible] | 3 | 5 | — |
| Thermal coefficient of expansion | 3 | 4 | 5 |
| Total | 12 | 16 | 15 |

• [illegible]

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TABLE 2

[illegible]

| [illegible] | [illegible] | [illegible] | [illegible] | EARTH WT | | MOON WT | |
|---|---|---|---|---|---|---|---|
| | | | | [illegible] | N | [illegible] | N |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 177.73 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 939.87 | 31.33 | 148.07 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 711.79 | 26.67 | 118.61 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 433.73 | 20.00 | 88.95 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 355.97 | 13.09 | 59.31 |

[illegible] GRAVITY

[illegible]

| [illegible] | [illegible] | [illegible] CAPACITY |
|---|---|---|
| | | N |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | 1186.14 |
| [illegible] | [illegible] | [illegible] |

[illegible]

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TABLE 3

Motor Torque and Horsepower Calculations    ME 4182

| | | |
|---|---|---|
| Brush Torque (in-lb) | 298 | 33.674 Nt-m |
| Brush Angular Velocity (rev/s) | 2.4 | 144.000 (rpm) |

| Motor Angular Velocity (rev/s) | (rpm) | Motor Torque (in-lb) | (oz-in) | (Nt-m) | Horsepower (Hp) | Brush to Motor Ratio |
|---|---|---|---|---|---|---|
| 23.333 | 1400 | 30.651 | 490.423 | 3.464 | 0.672 | 9.722 |
| 24.167 | 1450 | 29.594 | 473.512 | 3.344 | 0.672 | 10.069 |
| 25.000 | 1500 | 28.608 | 457.728 | 3.233 | 0.672 | 10.417 |
| 25.833 | 1550 | 27.685 | 442.963 | 3.128 | 0.672 | 10.764 |
| 26.667 | 1600 | 26.820 | 429.120 | 3.031 | 0.672 | 11.111 |
| 27.500 | 1650 | 26.007 | 416.116 | 2.939 | 0.672 | 11.458 |
| 28.333 | 1700 | 25.242 | 403.878 | 2.852 | 0.672 | 11.806 |
| 29.167 | 1750 | 24.521 | 392.338 | 2.771 | 0.672 | 12.153 |
| 30.000 | 1800 | 23.840 | 381.440 | 2.694 | 0.672 | 12.500 |
| 30.833 | 1850 | 23.196 | 371.131 | 2.621 | 0.672 | 12.847 |
| 31.667 | 1900 | 22.585 | 361.364 | 2.552 | 0.672 | 13.194 |
| 32.500 | 1950 | 22.006 | 352.098 | 2.487 | 0.672 | 13.542 |
| 33.333 | 2000 | 21.456 | 343.296 | 2.425 | 0.672 | 13.889 |
| 34.167 | 2050 | 20.933 | 334.923 | 2.365 | 0.672 | 14.236 |
| 35.000 | 2100 | 20.434 | 326.949 | 2.309 | 0.672 | 14.583 |
| 35.833 | 2150 | 19.959 | 319.345 | 2.255 | 0.672 | 14.931 |
| 36.667 | 2200 | 19.505 | 312.087 | 2.204 | 0.672 | 15.278 |
| 37.500 | 2250 | 19.072 | 305.152 | 2.155 | 0.672 | 15.625 |
| 38.333 | 2300 | 18.657 | 298.518 | 2.108 | 0.672 | 15.972 |
| 39.167 | 2350 | 18.260 | 292.167 | 2.063 | 0.672 | 16.319 |
| 40.000 | 2400 | 17.880 | 286.080 | 2.020 | 0.672 | 16.667 |
| 40.833 | 2450 | 17.515 | 280.242 | 1.979 | 0.672 | 17.014 |

```
A9: (F3) [W10] +B9/60
B9: [W10] 1400
C9: (F3) [W10] +$E$3*$F$4/B9
D9: (F3) [W10] +C9*16
E9: (F3) [W10] +C9*0.113
```

```
F9: (F3) [W10] (0.00074*B9*D9)/756
G9: (F3) [W10] +B9/$F$4
```

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VELOCITY = ACCELERATION * TIME = 1.635 * .451

VELOCITY= 0.74 m/sec

POTENTIAL ENERGY = MASS * GRAVITY * HEIGHT
= 36.27 * 1.635 * .333 = 19.75 JOULES

MAXIMUM MOMENTUM = VELOCITY * MASS = .74 * 36.27
= 26.84 Kg-m/sec

Approximate Bag Dimensions for Roll Calculations

| | | | | | | |
|---|---|---|---|---|---|---|
| VOLUME: | 1 | FT^3 | | | | |
| HEIGHT: | 1 | FT | | | | |
| DIAMETER: | 1.13 | FT | | | | |
| RADIUS: | 0.56 | FT | | | | |
| CIRCUM.: | 3.54 | FT | | | | |
| WIDTH FLAT BAG | 1.77 | FT | | | | |
| TOTAL GUIDE PATH WIDTH: | | | 1 | IN | 0.08 | FT |
| TOTAL ROLL WIDTH | 1.86 | FT | | | | |

Funnell iterations
Table no. 5

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TABLE 6

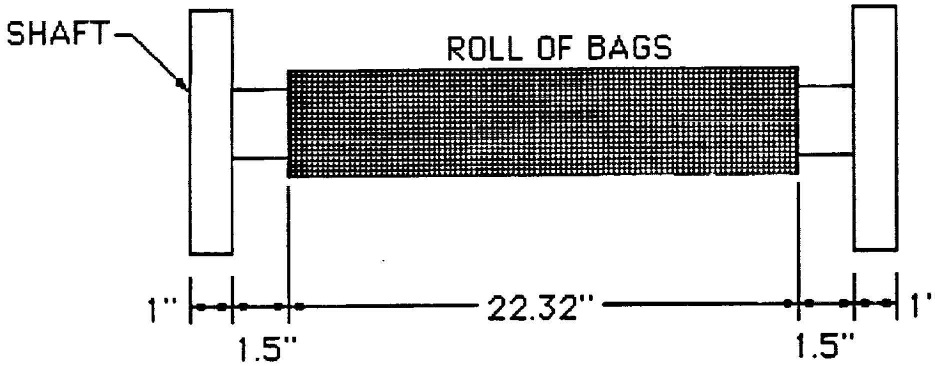
Roll of Bags Calculations ME 4182

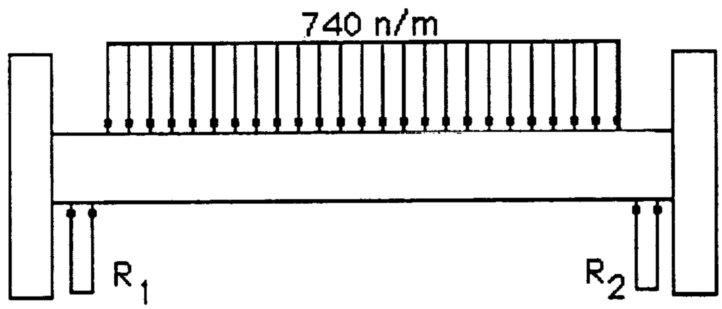
| | | |
|---|---|---|
| Shaft density (lb/in^3) Boron-6061 Al | 0.08486 | 1578.390 kg/m^3 |
| Bag material density (oz/yd^2) | 6.25 | 0.043 lb/ft^2 |
| Bag dimensions | | |
| Depth (ft) | 1.17 | 0.357 meter |
| Total width flat bag (ft) | 1.86 | 0.567 meter |
| Circumference (ft) | 3.55 | 1.082 meter |
| Flat bag thickness (mm) | 2 | 0.002 meter |
| Support Clearance (ft) | 0.125 | |
| Outside end pieces | 0.083 | |
| Safety Factor | 1.5 | |
| Maximum Moment (Nt-m) | 50.17 | |
| Sy (GPa) | 1109 | |
| Moon Gravity (m/s^2) | 1.67 | |

| Number of Bags | Mass (kg) | Moon Weight (Nt) | Volume (m^3) | Roll Radius (m) | Shaft Radius O. D. (m) | Shaft Radius I. D. (m) | Moon Shaft Weight (Nt) | Total Moon Weight (Nt) | Total Earth Weight (Nt) | Total Mass (kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| 400 | 32.708 | 54.623 | 0.162 | 0.305 | 0.05 | 0.04 | 0.002 | 54.625 | 327.749 | 33.410 |
| 425 | 34.753 | 58.037 | 0.172 | 0.315 | 0.05 | 0.04 | 0.002 | 58.039 | 348.233 | 35.498 |
| 450 | 36.797 | 61.451 | 0.182 | 0.324 | 0.05 | 0.04 | 0.002 | 61.453 | 368.716 | 37.586 |
| 475 | 38.841 | 64.865 | 0.192 | 0.332 | 0.05 | 0.04 | 0.002 | 64.867 | 389.200 | 39.674 |
| 500 | 40.885 | 68.278 | 0.202 | 0.341 | 0.05 | 0.04 | 0.002 | 68.281 | 409.683 | 41.762 |
| 525 | 42.930 | 71.692 | 0.212 | 0.349 | 0.05 | 0.04 | 0.002 | 71.694 | 430.167 | 43.850 |
| 550 | 44.974 | 75.106 | 0.222 | 0.357 | 0.05 | 0.04 | 0.002 | 75.108 | 450.650 | 45.938 |
| 575 | 47.018 | 78.520 | 0.233 | 0.365 | 0.05 | 0.04 | 0.002 | 78.522 | 471.134 | 48.026 |
| 600 | 49.062 | 81.934 | 0.243 | 0.372 | 0.05 | 0.04 | 0.002 | 81.936 | 491.617 | 50.114 |
| 625 | 51.107 | 85.348 | 0.253 | 0.380 | 0.05 | 0.04 | 0.002 | 85.350 | 512.101 | 52.202 |
| 650 | 53.151 | 88.762 | 0.263 | 0.387 | 0.05 | 0.04 | 0.002 | 88.764 | 532.585 | 54.290 |
| 675 | 55.195 | 92.176 | 0.273 | 0.395 | 0.05 | 0.04 | 0.002 | 92.178 | 553.068 | 56.378 |
| 700 | 57.239 | 95.590 | 0.283 | 0.402 | 0.05 | 0.04 | 0.002 | 95.592 | 573.552 | 58.466 |
| 725 | 59.284 | 99.004 | 0.293 | 0.409 | 0.05 | 0.04 | 0.002 | 99.006 | 594.035 | 60.554 |
| 750 | 61.328 | 102.418 | 0.303 | 0.416 | 0.05 | 0.04 | 0.002 | 102.420 | 614.519 | 62.642 |
| 775 | 63.372 | 105.832 | 0.313 | 0.422 | 0.05 | 0.04 | 0.002 | 105.834 | 635.002 | 64.730 |
| 800 | 65.417 | 109.246 | 0.323 | 0.429 | 0.05 | 0.04 | 0.002 | 109.248 | 655.486 | 66.818 |
| 825 | 67.461 | 112.660 | 0.334 | 0.436 | 0.05 | 0.04 | 0.002 | 112.662 | 675.969 | 68.906 |
| 850 | 69.505 | 116.073 | 0.344 | 0.442 | 0.05 | 0.04 | 0.002 | 116.075 | 696.453 | 70.994 |
| 875 | 71.549 | 119.487 | 0.354 | 0.448 | 0.05 | 0.04 | 0.002 | 119.489 | 716.936 | 73.082 |
| 900 | 73.594 | 122.901 | 0.364 | 0.455 | 0.05 | 0.04 | 0.002 | 122.903 | 737.420 | 75.170 |
| 925 | 75.638 | 126.315 | 0.374 | 0.461 | 0.05 | 0.04 | 0.002 | 126.317 | 757.904 | 77.258 |
| 950 | 77.682 | 129.729 | 0.384 | 0.467 | 0.05 | 0.04 | 0.002 | 129.731 | 778.387 | 79.346 |
| 975 | 79.726 | 133.143 | 0.394 | 0.473 | 0.05 | 0.04 | 0.002 | 133.145 | 798.871 | 81.434 |
| 1000 | 81.771 | 136.557 | 0.404 | 0.479 | 0.05 | 0.04 | 0.002 | 136.559 | 819.354 | 83.522 |
| 1025 | 83.815 | 139.971 | 0.414 | 0.485 | 0.05 | 0.04 | 0.002 | 139.973 | 839.838 | 85.610 |

```
B20: (F3) [W9] +$G$4*$F$8*$F$6*A20*(0.45359237)
C20: (F3) [W11] +B20*$F$15
D20: (F3) [W8] +A20*$G$6*$G$7*$G$9
E20: (F3) [W10] (D20/($G$7*@PI)+F20^2)^0.5
F20: (F2) [W9] 0.05
G20: [W10] 0.04
H20: (F3) [W11] (($F$3*@PI*(F20^2-G20^2)*($G$7+$F$10))+2*($F$3*@PI*(F20+$F$11)^2*0.5))*($F$15/4)
I20: (F3) [W11] +C20+H20
J20: (F3) [W11] +I20*6
K20: (F3) [W10] +J20/9.81
```

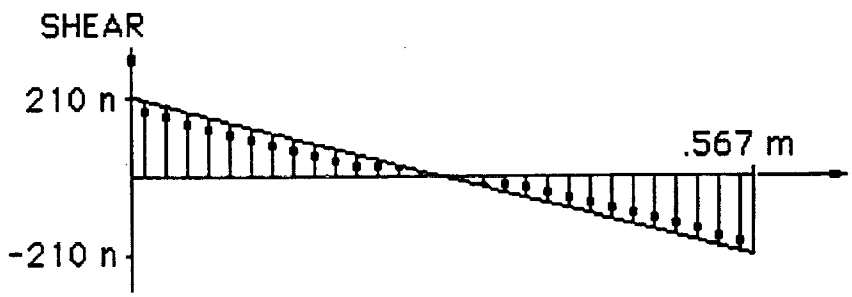
TABLE 7




$$R1 = 740\ n/m(.567\ m)/2$$
$$R1 = 210\ n = -R2$$

SHEAR DIAGRAM




$$M = (1/2)(.567\ m)(210\ n)$$
$$M = 59.5\ n\text{-}m$$

MOMENT DIAGRAM

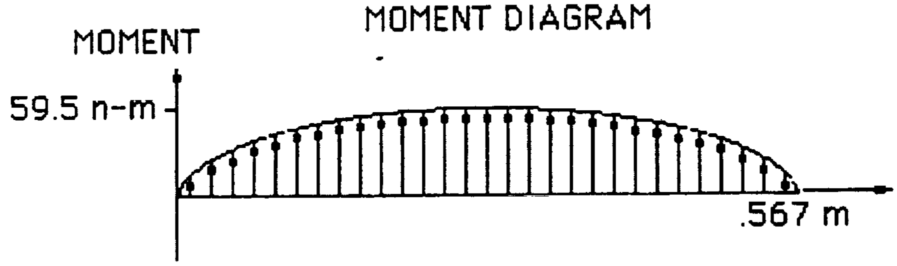


TABLE 8

[illegible] ROD DESIGN

[illegible] IS FOUND BY SUMMING THE MOMENTS

SUM OF MOMENTS = [illegible] WT * MOMENT ARM - ROD FORCE * BAG DIAM
[illegible] ROD FORCE * 1.1[illegible]
[illegible]

[illegible] STRAIN GAUGE ARE TAKEN FROM FIGURE
[illegible] FOR FINDING THE
[illegible] STRAIN GAUGE

[illegible]
[illegible]

| STRAIN AT GAUGE | OUTER RADIUS m | INNER RADIUS m | BAG FORCE Nt | MAGNET WT Nt | TOTAL FORCE Nt | STRAIN MOMENT Nt-m | FIXED MOMENT Nt-m | MAXIM DEFL m | MAX BEND STRESS MPa |
|---|---|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | 0 | 29.65 | 1.779 | 2.372 | 0.001138 | 282.99 |
| [illegible] | [illegible] | [illegible] | 29.65 | 0 | 29.65 | 1.779 | 2.372 | 2.64E-05 | 6.59 |
| [illegible] | [illegible] | [illegible] | [illegible] | 0 | 29.65 | 1.779 | 2.372 | 1.54E-05 | 3.84 |
| [illegible] | [illegible] | [illegible] | 29.65 | 0 | 29.65 | 1.779 | 2.372 | 8.21E-05 | 14.35 |
| [illegible] | [illegible] | [illegible] | [illegible] | 0 | 29.65 | 1.779 | 2.372 | 5.11E-05 | 8.93 |
| [illegible] | [illegible] | [illegible] | 29.65 | 0 | 29.65 | 1.779 | 2.372 | 4.23E-05 | 7.39 |
| [illegible] | [illegible] | [illegible] | [illegible] | 0 | 29.65 | 1.779 | 2.372 | 0.00187 | 233.42 |
| [illegible] | [illegible] | [illegible] | 29.65 | 0 | 29.65 | 1.779 | 2.372 | 0.000246 | 30.69 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 29.65 | 1.779 | 2.372 | 0.000167 | 20.88 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 29.65 | [illegible] | 2.372 | 0.000149 | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 2.372 | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1.779 | 2.372 | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

[illegible]

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TABLE 9

PROGRAM LISTING FOR STRAIN GAUGE CONTROL WITH THE MC68HC11A8 CHIP

```
         ORG $C000
         LDAB #$80     * LOAD ACC. A WITH 90 HEX (144 DECIMAL)
         STAB $1039    * STORE ACC. A IN OPTION REGISTER
         LDAB #$28     * LOAD ACC. A WITH 28 HEX (32 DECIMAL)
PAUSE    DECB          * PAUSE TO ALLOW A/D CHARGE TO BUILD
         BNE PAUSE     * BRANCH UNTIL A/D IS CHARGED
BEGIN    LDAA #$10     * LOAD ACCUMULATOR A WITH 20 HEX
         STAA $1030    * STORE ACC. A TO SET ADCTL TO SCAN CONTINUOUSLY
PAUSE2   LDAB $1030    * LOAD ACC. B WITH $1030  A/D RESULT REGISTER
         ANDB #$80     * CHECK IF CONVERSION FLAG IS SET
         BEQ PAUSE2    * BRANCH UNTIL A/D CONVERSION FLAG IS SET
         LDAA $1032    * LOAD ACC. A WITH A/D RESULT REGISTER
         STAA $C0FF    * STORE A/D RESULT REGISTER IN MEMORY
         LDX #$0000    * CLEARS X REGISTER
         STX $C100     * STORES X REGISTER IN MEMORY
         ANDA #$80     * CHECK BIT 7 OF RESULT REGISTER
         BEQ LOOP1     * IF RESULT REGISTER IS NOT SET THEN BRANCH
         LDD #$09C4    * LOAD DOUBLE ACC. D WITH 2500 MILLIVOLTS
         STD $C100     * STORE ACC. D IN MEMORY
LOOP1    LDAA $C0FF    * LOAD ACC. A WITH ORIGINAL A/D RESULT REGISTER
         ANDA #$40     * CHECK BIT 6 OF RESULT REGISTER
         BEQ LOOP2     * IF RESULT REGISTER IS NOT SET THEN BRANCH
         LDD $C100     * LOAD DOUBLE ACC. D
         ADDD #$04E2   * ADD 4E2 HEX (1250 MILLIVOLTS) TO $C100
         STD $C100     * STORE THE ADDD ABOVE IN $C100
LOOP2    LDAA $C0FF    * LOAD ACC. A WITH ORIGINAL A/D RESULT REGISTER
         ANDA #$20     * CHECK BIT 5 OF RESULT REGISTER
         BEQ LOOP3     * IF RESULT REGISTER IS NOT SET THEN BRANCH
         LDD $C100     * LOAD DOUBLE ACC. D
         ADDD #$0271   * ADD 271 HEX (625 MILLIVOLTS) TO $C100
         STD $C100     * STORE THE ADDD ABOVE IN $C100
LOOP3    LDAA $C0FF    * LOAD ACC. A WITH ORIGINAL A/D RESULT REGISTER
         ANDA #$10     * CHECK BIT 4 OF RESULT REGISTER
         BEQ LOOP4     * IF RESULT REGISTER IS NOT SET THEN BRANCH
         LDD $C100     * LOAD DOUBLE ACC. D
         ADDD #$0139   * ADD 139 HEX (312.5 MILLIVOLTS) TO $C100
         STD $C100     * STORE THE ADDD ABOVE IN $C100
LOOP4    LDAA $C0FF    * LOAD ACC. A WITH ORIGINAL A/D RESULT REGISTER
         ANDA #$08     * CHECK BIT 3 OF RESULT REGISTER
         BEQ LOOP5     * IF RESULT REGISTER IS NOT SET THEN BRANCH
         LDD $C100     * LOAD DOUBLE ACC. D
         ADDD #$9C     * ADD 9C HEX (156.2 MILLIVOLTS) TO $C100
         STD $C100     * STORE THE ADDD ABOVE IN $C100
LOOP5    LDAA $C0FF    * LOAD ACC. A WITH ORIGINAL A/D RESULT REGISTER
         ANDA #$04     * CHECK BIT 2 OF THE RESULT REGISTER
         BEQ LOOP4     * IF RESULT REGISTER IS NOT SET THEN BRANCH
         LDD $C100     * LOAD DOUBLE ACC. D
         ADDD #$4E     * ADD 4E HEX (78.1 MILLIVOLTS) TO $C100
         STD $C100     * STORE THE ADD ABOVE IN $C100
```

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```
LOOP6    LDAA $C0FF    * LOAD ACC. A WITH ORIGINAL A/D RESULT REGISTER
         ANDA #$02     * CHECK BIT 2 OF THE RESULT REGISTER
         BEQ LOOP7     * IF RESULT REGISTER IS NOT SET THEN BRANCH
         LDD $C100     * LOAD DOUBLE ACC. D
         ADDD #$27     * ADD 27 HEX (39.1 MILLIVOLTS) TO $C100
         STD $C100     * STORE THE ADD ABOVE IN $C100
LOOP7    LDAA $C0FF    * LOAD ACC. A WITH ORIGINAL A/D RESULT REGISTER
         ANDA #$01     * CHECK BIT 2 OF THE RESULT REGISTER
         BEQ LOOP8     * IF RESULT REGISTER IS NOT SET THEN BRANCH
         LDD $C100     * LOAD DOUBLE ACC. D
         ADDD #$14     * ADD 14 HEX (19.5 MILLIVOLTS) TO $C100
         STD $C100     * STORE THE ADD ABOVE IN $C100
LOOP8    LDD $C100     * LOAD DOUBLE ACC. D WITH $C100
         LDX #1000     * LOAD REGISTER X WITH 1000 DECIMAL
         IDIV          * INTERGER DIVISION ON ACC. D AND REGISTER X
         STX $C150     * STORE QUOTIENT IN $C150
         LDX #100      * LOAD REGISTER X WITH 100 DECIMAL
         IDIV          * INTERGER DIVISION ON ACC. D AND REGISTER X
         STX $C152     * STORE QUOTIENT IN $C152
         LDX #10       * LOAD REGISTER X WITH 10 DECIMAL
         IDIV          * INTEGER DIVISION ON ACC. D AND REGISTER X
         STX $C154     * STORE QUOTIENT IN $C154
         LDX #1        * LOAD REGISTER X WITH 1 DEIMAL
         IDIV          * INTEGER DIVISION ON ACC. D AND REGISTER X
         STX $C156     * STORE QUOTIENT IN $C156
         LDAA $C151    * LOAD ACC. A WITH LOW BYTE OF FIRST DIVISION
         ADDA #$30     * ADD $30 HEX TO ACC. A
         JSR $FFB8     * JUMP TO SUBROUTINE TO GET ASCII CODE
         LDAA $C153    * LOAD ACC. A WITH LOW BYTE OF SECOND DIVISION
         ADDA #$30     * ADD $30 HEX TO ACC. A
         JSR $FFB8     * JUMP TO SUBROUTINE TO GET ASCII CODE
         LDAA $C155    * LOAD ACC. A WITH LOW BYTE OF THIRD DIVISION
         ADDA #$30     * ADD $30 HEX TO ACC. A
         JSR $FFB8     * JUMP TO SUBROUTINE TO GET ASCII CODE
         LDAA $C157    * LOAD ACC. A WITH LOW BYTE OF FOURTH DIVISION
         ADDA #$30     * ADD $30 HEX TO ACC. A
         JSR $FFB8     * JUMP TO SUBROUTINE TO GET ASCII CODE
         LDAA #$20     * LOAD ACC. A WITH LOW BYTE OF FIFTH DIVISION
         JSR $FFB8     * JUMP TO SUBROUTINE TO GET ASCII CODE
         LDAA #$6D     * LOAD ACC. A WITH LOW BYTE OF SIX DIVISION
         JSR $FFB8     * JUMP TO SUBROUTINE TO GET ASCII CODE
         LDAA #$56     * LOAD ACC. A WITH LOW BYTE OF SEVENTH DIVISION
         JSR $FFB8     * JUMP TO SUBROUTINE TO GET ASCII CODE
         LDAA #$0D     * LOAD ACC. A WITH LOW BYTE OF EIGHT DIVISION
         JSR $FFB8     * JUMP TO SUBROUTINE TO GET ASCII CODE
         LDAA #$05     * START OF TIMING LOOP
WAIT1    LDY #$DF26    * TIMIING LOOP
WAIT2    DEY           * DECREMENT PART OF TIMING LOOP
         BNE WAIT2     * TIMING LOOP
         DECA          * TIMING LOOP
```

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```
BNE WAIT1     * TIMING LOOP
JMP BEGIN     * JUMP BACK TO THE BEGINNING FOR ANOTHER LOOP
SWI
```

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TABLE 10

DISK TORQUE CALCULATIONS

REGOLITH BAGGING MACHINE LOWERRING CLUTCH

| SLOT ANGLE (DEG) | SLOT ANGLE (RAD) | TORQUE (N-M) | TORQUE (IN-LBF) |
|---|---|---|---|
| 60 | 1.05 | 5.22 | 42.31 |
| 54 | 0.94 | 6.13 | 49.74 |
| 48 | 0.84 | 6.98 | 56.62 |
| 42 | 0.73 | 7.76 | 62.88 |
| 36 | 0.63 | 8.44 | 68.45 |
| 30 | 0.52 | 9.04 | 73.28 |
| 24 | 0.42 | 9.53 | 77.30 |
| 18 | 0.31 | 9.93 | 80.47 |
| 12 | 0.21 | 10.21 | 82.77 |
| 6 | 0.10 | 10.38 | 84.15 |
| 0 | 0.00 | 10.44 | 84.61 |
| -6 | -0.10 | 10.38 | 84.15 |
| -12 | -0.21 | 10.21 | 82.77 |
| -18 | -0.31 | 9.93 | 80.47 |
| -24 | -0.42 | 9.53 | 77.30 |
| -30 | -0.52 | 9.04 | 73.28 |
| -36 | -0.63 | 8.44 | 68.45 |
| -42 | -0.73 | 7.76 | 62.88 |
| -48 | -0.84 | 6.98 | 56.62 |
| -54 | -0.94 | 6.13 | 49.74 |
| -60 | -1.05 | 5.22 | 42.31 |
| AVERAGE TORQUE | | 8.72 | 70.67 |

# L2 LIGHT SERIES

L2 Light Series with dry type bronze metallic friction discs and adjustable torque for overload protection or constant torque. Not recommended for operation in oil. Oilite bushings require no lubrication.

## COIL-SPRING TYPE

For installation requiring extra close adjustment or low torque range down to 1/2 lb.-in. Offered in both regular and double capacity and with heavy, medium or light springs. The number of springs used can be varied to develop the exact torque range needed.

Clutch-coupling models are used to directly connect two shaft ends. Excellent shaft alignment should be maintained within .005" parallel and 1/4° angular.

Models L2-1-313XA and L2-1-323XA feature a setscrew to anchor the hub on the shaft. Slightly more shaft length is needed for mounting.

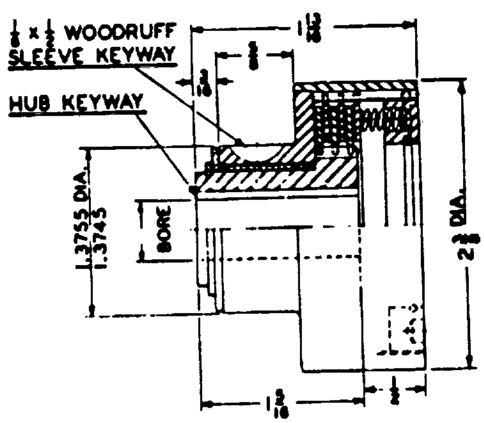
Maximum Operating Speed—1800 RPM

#SK-2172 Spanner Wrench for all size L2 adjusting nuts

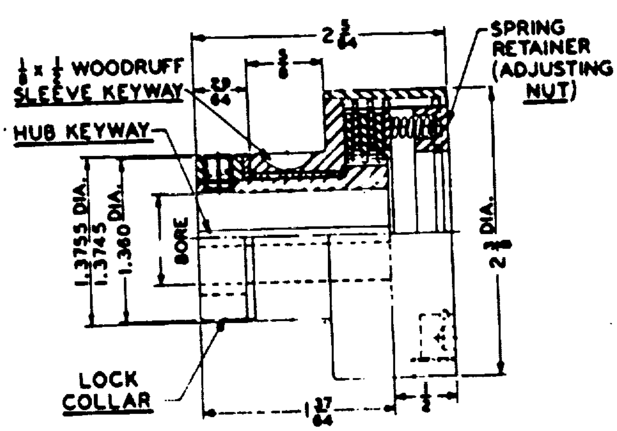
| | |
|---|---|
| 1/2" bore 1/8" x 1/16" keyway<br>5/8" bore 3/16" x 3/32" keyway<br>3/4" bore 3/16" x 1/32" keyway | 1/2" bore 1/8" x 1/16" keyway<br>5/8" bore 3/16" x 3/32" keyway<br>3/4" bore 3/16" x 3/32" keyway (sleeve)<br>3/16" x 1/32" keyway (hub) |

| | | |
|---|---|---|
| L2-1-313A<br>L2-1-323A<br>L2-1-313XA<br>L2-1-323XA | 3 lbs. | Regular<br>8 Heavy Springs—6 to 88 lb.-in.<br>8 Medium Springs—3 to 30 lb.-in.<br>8 Light Springs—1/2 to 6 lb.-in. |
| • DL2-1-313A<br>• DL2-1-323A<br>• DL2-1-313XA<br>• DL2-1-323XA | 3 lbs. | Double Capacity<br>16 Heavy Springs—12 to 176 lb.-in.<br>16 Medium Springs—6 to 60 lb.-in.<br>16 Light Springs—1 to 12 lb.-in. |

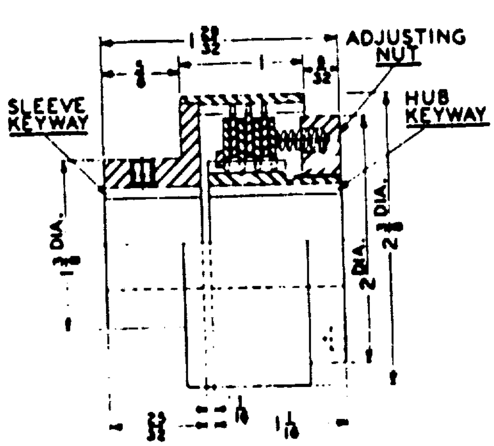
• Letter "D" in size denotes Double Capacity



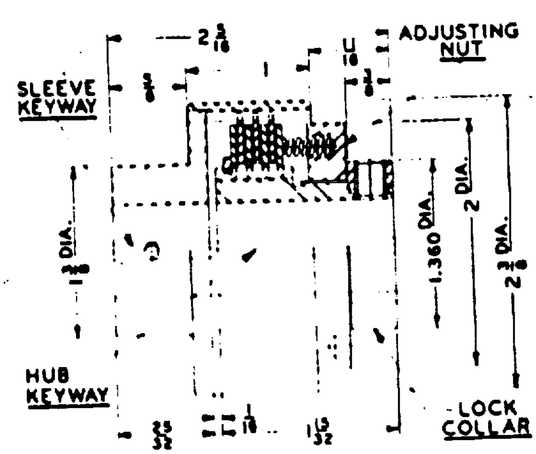

L2-1-313A




L2-1-313XA




L2-1-323A




L2-1-323XA



1367 G-04

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# L2 LIGHT SERIES

## DISC-SPRING TYPE

For the average installation and normal duty in a torque range one lb.-ft. (12 lb.-in.) and higher where the exact setting is not critical. Available in regular or double capacity. Excellent for overload protection in all kinds of drive systems.

Clutch-coupling models are used to connect two shaft ends and close alignment is required within .005" parallel and 1/4° angular.

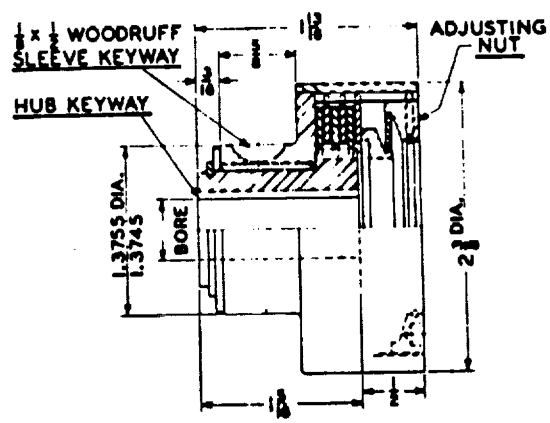
Models L2-1-313X and L2-1-323X feature a setscrew to anchor the hub on the shaft. Slightly more shaft length is needed for mounting.

Maximum Operating Speed—1800 RPM

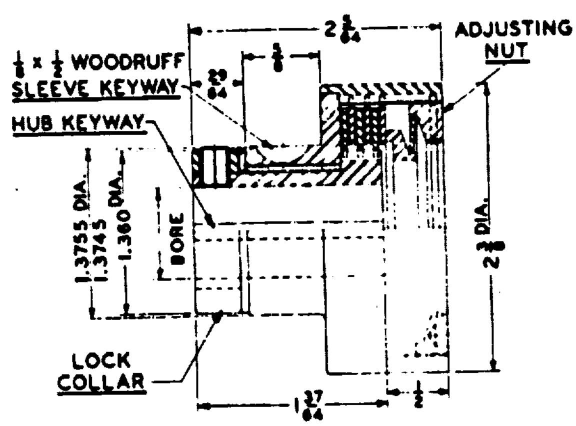
#SK-2172 Spanner Wrench for all size L2 adjusting nuts

| | | |
|---|---|---|
| L2-1-313<br>L2-1-323<br><br>L2-1-313X<br>L2-1-323X | 3 lbs. | Regular:<br>12 to 108 lb.-in.<br>(Single Disc Spring) |
| • DL2-1-313<br>• DL2-1-323<br><br>• DL2-1-313X<br>• DL2-1-323X | 3 lbs. | Double Capacity:<br>24 to 216 lb.-in.<br>(Two Disc Springs) |

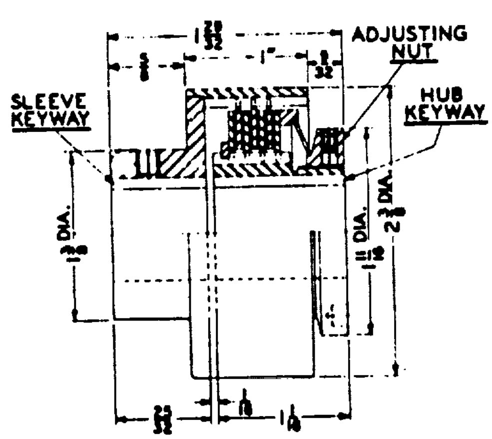
• Letter "D" in size denotes Double Capacity.



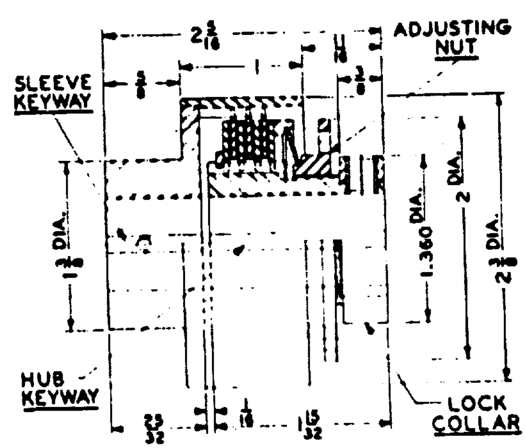

L2-1-313




L2-1-313X




L2-1-323




L2-1-323X

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FIGURE 1
DIMENSIONS IN METERS
NOT TO SCALE

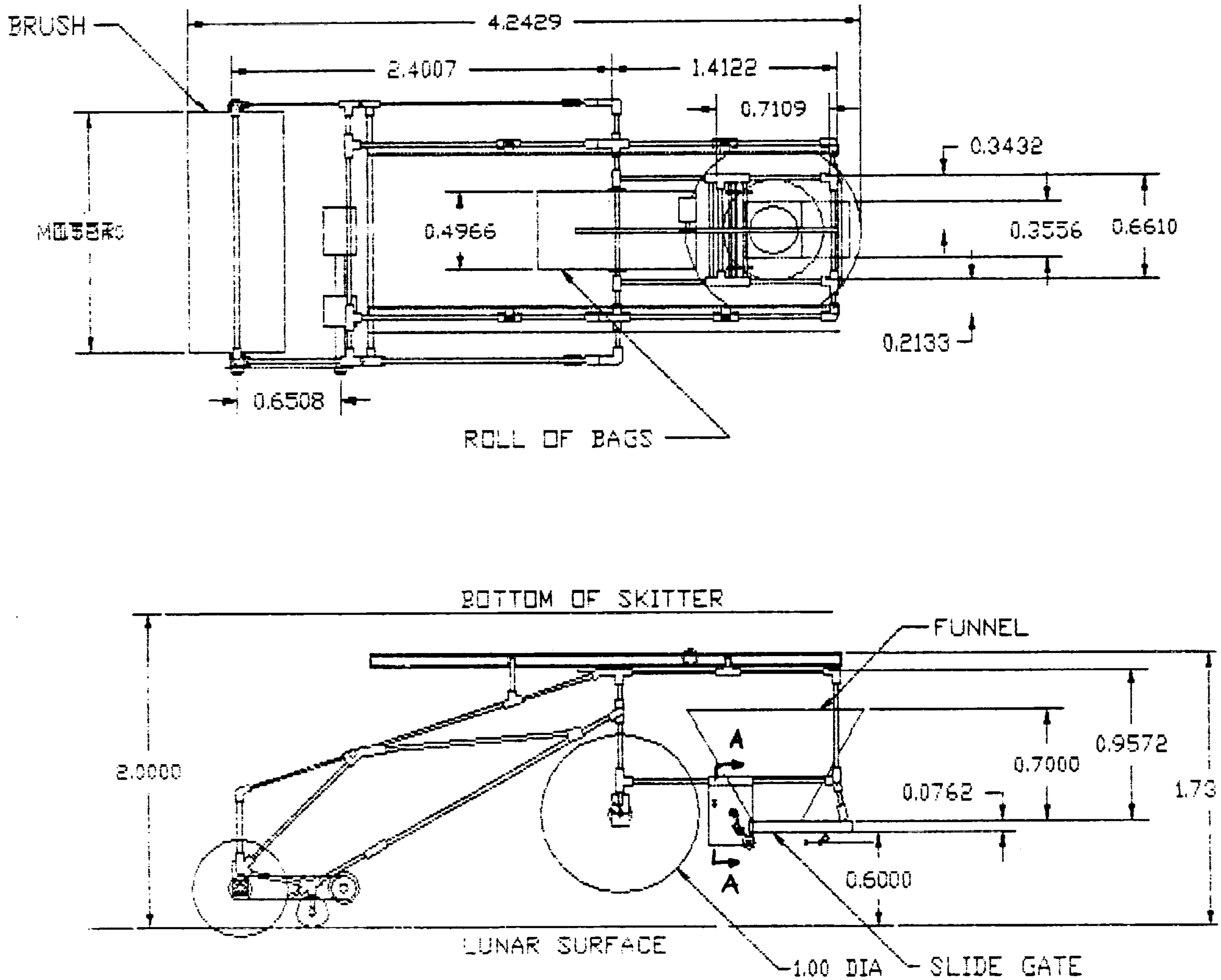
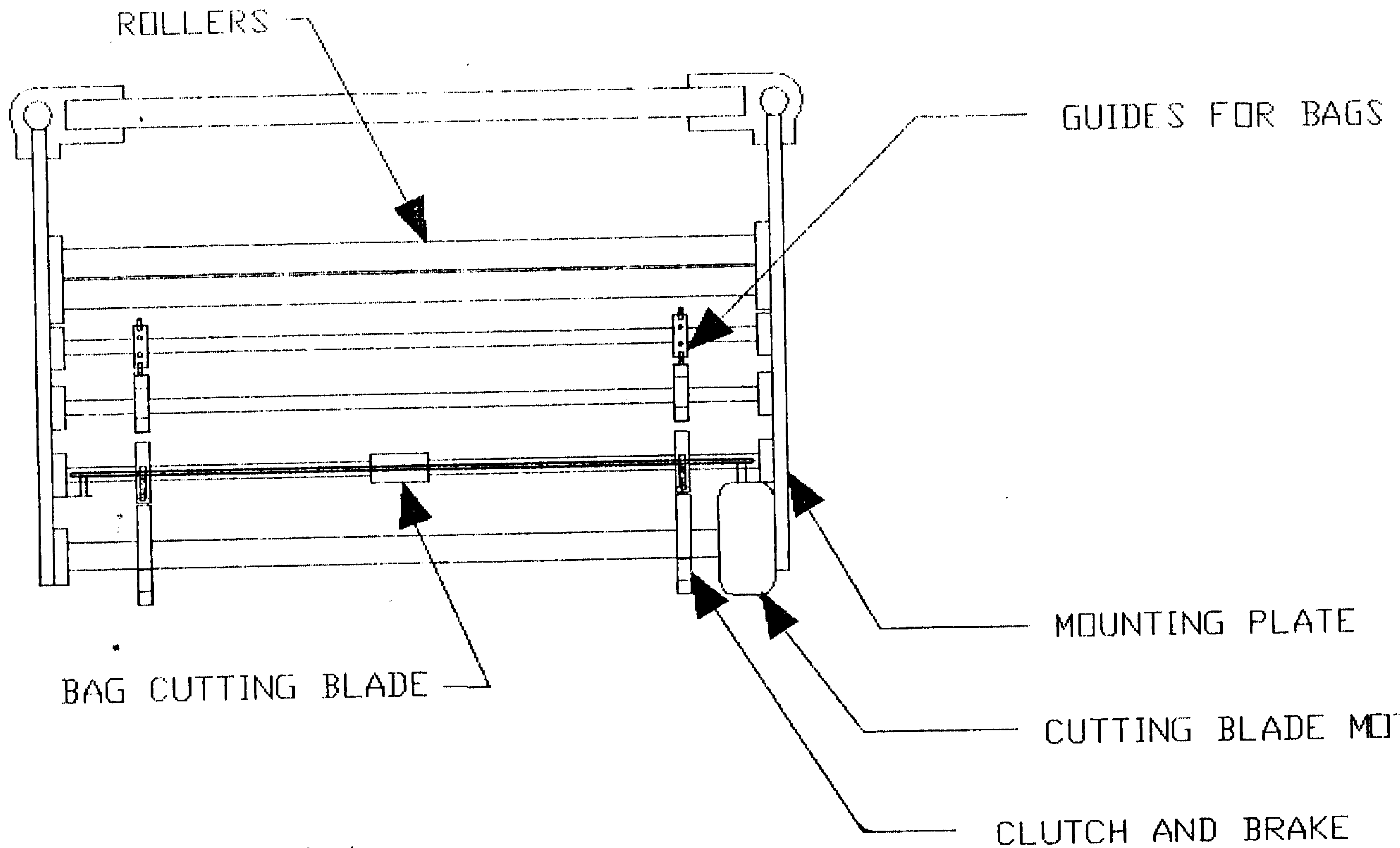


FIGURE 2




SECTION A-A

FIGURE 3

**Roll Replacement Schematic**

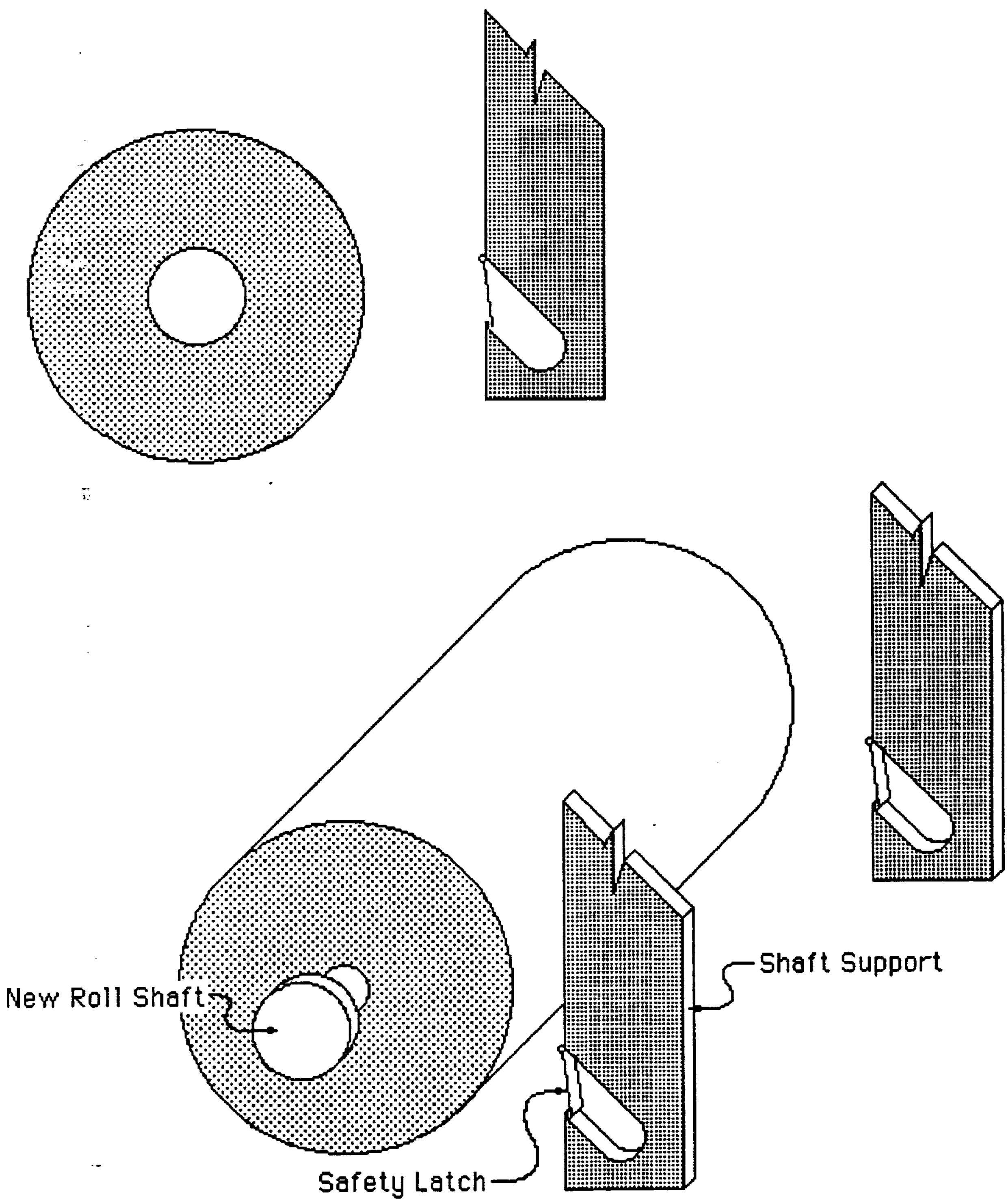
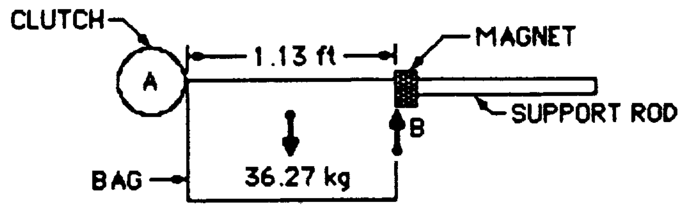


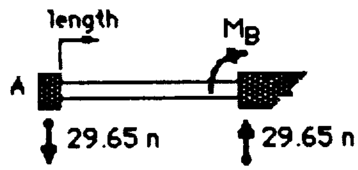
FIGURE 4




$\Sigma M_A = 0$

$-36.27\ \text{kg}\ (1.635\ \text{m/sec}^2)\ (1.13\ \text{ft}/2) + B\ 1.13\ \text{ft} = 0$

$B = 29.65\ \text{n}$




$M_A = 0$

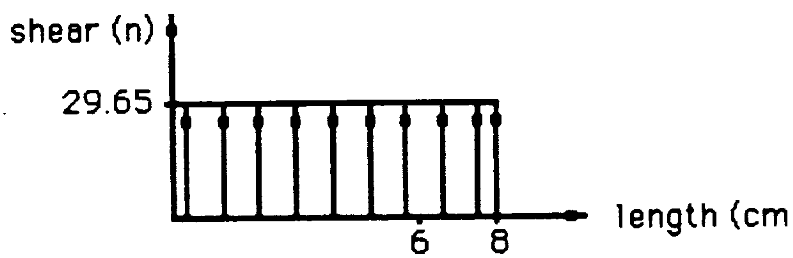
$M_B = 29.65\ \text{n}\ (.08\ \text{m})$

$M_B = 2.372\ \text{j}$

$M = 29.65\ \text{n}\ (.06\ \text{m})$

$M = 1.78\ \text{j}$

**SHEAR DIAGRAM**




**MOMENT DIAGRAM**

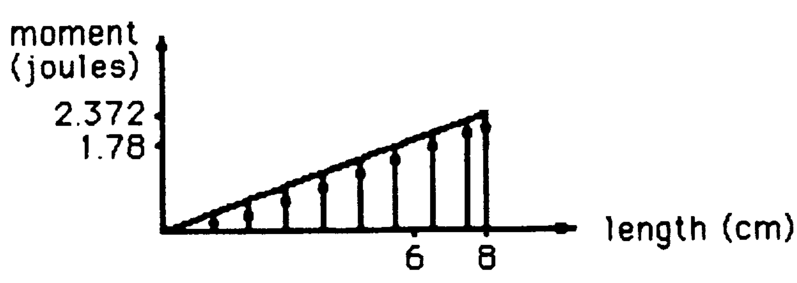
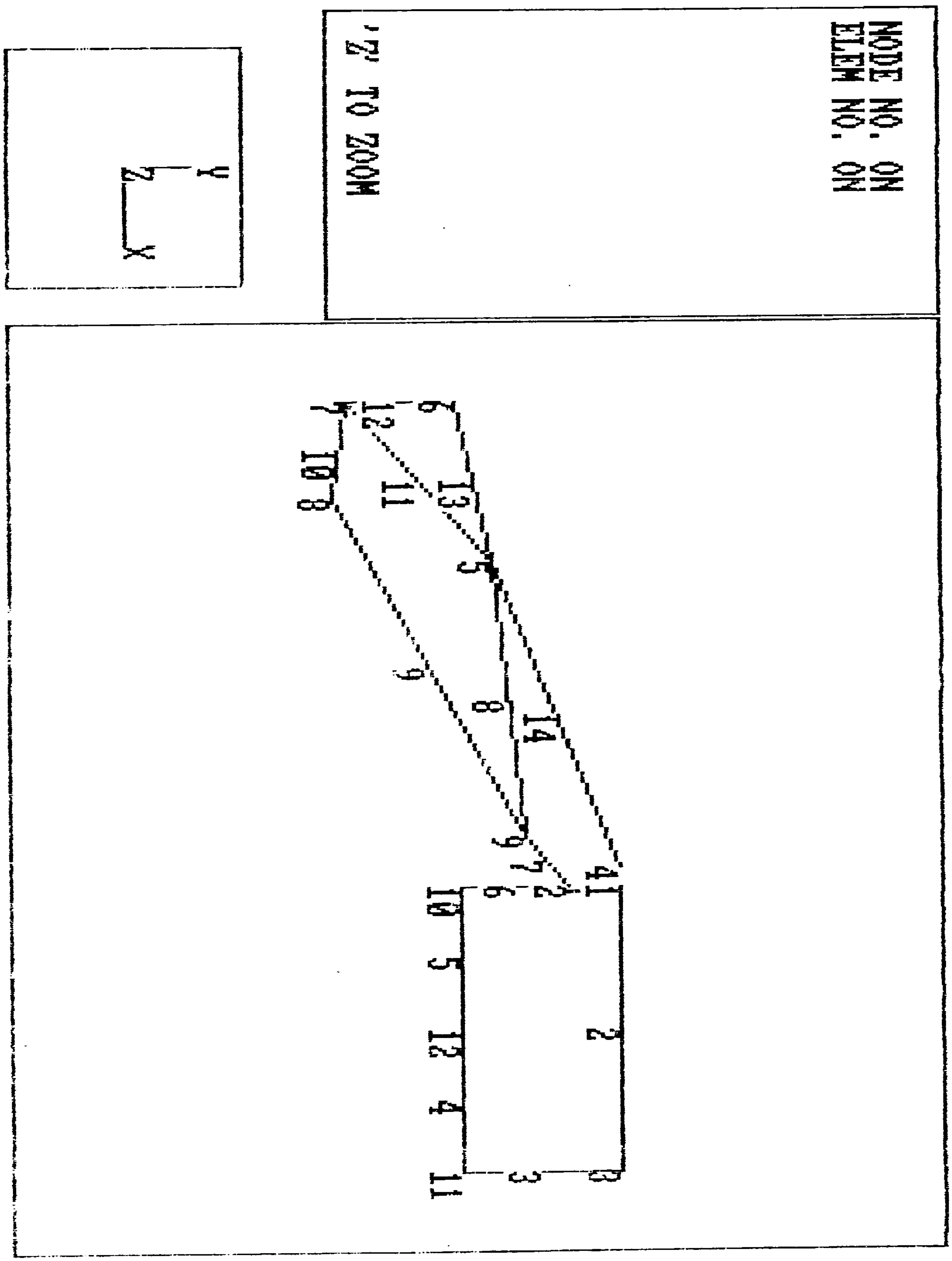


FIGURE 5



I H P E  ANALYSIS MODULE  VERSION 1.1  DEMONSTRATION VERSION

INPUT FILE: mmmm.in  DATE: 1/ 1/1980 TIME: 02:54:08

No. of nodes........... 12
No. of elements........ 14
No. of materials....... 1
No. of property sets... 1

I H P E  ANALYSIS MODULE  VERSION 1.1  DEMONSTRATION VERSION

NODAL COORDINATES

| NODE | X | Y |
|---|---|---|
| 1 | .0000 | .0000 |
| 2 | .0000 | -.2570 |
| 3 | 1.4122 | .0000 |
| 4 | -.1000 | .0000 |
| 5 | -1.6000 | -.6380 |
| 6 | -2.4000 | -.8170 |
| 7 | -2.4000 | -1.3600 |
| 8 | -1.9200 | -1.4300 |
| 9 | -.2500 | -.4790 |
| 10 | .0000 | -.8000 |
| 11 | 1.4122 | -.8000 |
| 12 | .7060 | -.8000 |

I H P E  ANALYSIS MODULE  VERSION 1.1  DEMONSTRATION VERSION

ELEMENT DEFINITIONS

| ELEM | MATL | PROP | TYPE | NODE 1 | NODE 2 |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 10 | 1 | 2 |
| 2 | 1 | 1 | 10 | 1 | 3 |
| 3 | 1 | 1 | 10 | 3 | 11 |
| 4 | 1 | 1 | 10 | 11 | 12 |
| 5 | 1 | 1 | 10 | 12 | 10 |
| 6 | 1 | 1 | 10 | 10 | 2 |
| 7 | 1 | 1 | 10 | 2 | 9 |

| | | | | | |
|---|---|---|---|---|---|
| 8 | 1 | 1 | 10 | 9 | 5 |
| 9 | 1 | 1 | 10 | 9 | 8 |
| 10 | 1 | 1 | 10 | 8 | 7 |
| 11 | 1 | 1 | 10 | 7 | 5 |
| 12 | 1 | 1 | 10 | 7 | 6 |
| 13 | 1 | 1 | 10 | 6 | 5 |
| 14 | 1 | 1 | 10 | 5 | 4 |



MATERIAL PROPERTIES

| MATL NO | E | NU | DENS | ALPHA |
|---|---|---|---|---|
| 1 | .2200000E+12 | .3340000 | 1578.000 | .0000000 |



PHYSICAL PROPERTIES

PROPERTY SET 1 .5070000E-03 .0000000 .0000000 .0000000
.0000000
.0000000 .0000000 .0000000 .0000000
.0000000



SPECIFIED NODAL DISPLACEMENTS

NODE DOF SPEC. DISPL



APPLIED NODAL FORCES

| NODE | DOF | FORCE |
|---|---|---|
| 3 | 2 | 231.5000 |
| 5 | 2 | 231.5000 |
| 7 | 1 | 82.33000 |
| 7 | 2 | -74.17900 |

| | | |
|---|---|---|
| 8 | 1 | -82.33000 |
| 8 | 2 | -37.11000 |
| 10 | 2 | -65.17000 |
| 11 | 2 | -147.9700 |
| 12 | 2 | -147.9700 |



SPECIFIED NODAL TEMPERATURES

NODE TEMP



ELEMENT LOADS

ELEM FACE VALUE



TIME .00000

PROPORTIONAL LOAD 1.0000

ITERATION 1

G-LOAD DIR= 0

MAGNITUDE= .000



NODAL DISPLACEMENT SOLUTION TIME .00000E+00 LOAD STEP 1 ITERATIO
N 1

| NODE | X-COORD | Y-COORD | X-TRANS | Y-TRANS |
|---|---|---|---|---|
| 1 | .0000 | .0000 | .0000 | 4.384 |
| 2 | .0000 | -.2570 | 30.06 | 4.384 |
| 3 | 1.412 | .0000 | .0000 | 83.53 |
| 4 | -.1000 | .0000 | -16.12 | .0000 |
| 5 | -1.600 | -.6380 | 34.78 | -119.7 |

| | | | | |
|---|---|---|---|---|
| 6 | -2.400 | -.8170 | 14.73 | -30.07 |
| 7 | -2.400 | -1.360 | -46.07 | -30.07 |
| 8 | -1.920 | -1.430 | -27.38 | 98.08 |
| 9 | -.2500 | -.4790 | 18.66 | 17.23 |
| 10 | .0000 | -.8000 | .0000 | 4.384 |
| 11 | 1.412 | -.8000 | .0000 | 83.53 |
| 12 | .7060 | -.8000 | .0000 | -148.0 |

ELASTIC STRAIN ENERGY INCREMENT= -15467.2

1 H P E ANALYSIS MODULE VERSION 1.1 DEMONSTRATION VERSION

ELEMENT STRESS SOLUTION TIME .00000E+00 LOAD STEP 1 ITERATION

| ELEM | MATL | PROP | TYPE | STRAIN | STRESS | FORCE |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 10 | .0000 | .0000 | .0000 |
| 2 | 1 | 1 | 10 | .0000 | .0000 | .0000 |
| 3 | 1 | 1 | 10 | .0000 | .0000 | .0000 |
| 4 | 1 | 1 | 10 | .0000 | .0000 | .0000 |
| 5 | 1 | 1 | 10 | .0000 | .0000 | .0000 |
| 6 | 1 | 1 | 10 | .8782E-06 | .1932E+06 | 97.95 |
| 7 | 1 | 1 | 10 | .0000 | .0000 | .0000 |
| 8 | 1 | 1 | 10 | -.1403E-05 | -.3087E+06 | -156.5 |

| ELEM | MATL | PROP | TYPE | STRAIN | STRESS | FORCE |
|---|---|---|---|---|---|---|
| 9 | 1 | 1 | 10 | .0000 | .0000 | .0000 |

| ELEM | MATL | PROP | TYPE | STRAIN | STRESS | FORCE |
|---|---|---|---|---|---|---|
| 10 | 1 | 1 | 10 | -.7864E-05 | -.1730E+07 | -877.2 |

| ELEM | MATL | PROP | TYPE | STRAIN | STRESS | FORCE |
|---|---|---|---|---|---|---|
| 11 | 1 | 1 | 10 | .1062E-04 | .2336E+07 | 1185. |

| ELEM | MATL | PROP | TYPE | STRAIN | STRESS | FORCE |
|---|---|---|---|---|---|---|
| 12 | 1 | 1 | 10 | .0000 | .0000 | .0000 |

| ELEM | MATL | PROP | TYPE | STRAIN | STRESS | FORCE |
|---|---|---|---|---|---|---|
| 13 | 1 | 1 | 10 | .4072E-05 | .8958E+06 | 454.2 |

| ELEM | MATL | PROP | TYPE | STRAIN | STRESS | FORCE |
|---|---|---|---|---|---|---|
| 14 | 1 | 1 | 10 | -.2340E-05 | -.5149E+06 | -261.0 |

1 H P E ANALYSIS MODULE VERSION 1.1 DEMONSTRATION VERSION

NODAL REACTIONS

| NODE | 1 DOF | 2 DOF |
|---|---|---|
| 1 | .0000E+00 | .0000E+00 |
| 2 | .0000E+00 | .9795E+02 |
| 3 | .0000E+00 | .0000E+00 |
| 4 | -.2402E+03 | -.1022E+03 |
| 5 | .1718E+04 | .1013E+04 |
| 6 | -.4432E+03 | -.9916E+02 |
| 7 | -.1137E+02 | -.9202E+03 |
| 8 | -.8680E+03 | .1266E+03 |
| 9 | -.1554E+03 | -.1831E+02 |
| 10 | .0000E+00 | -.9795E+02 |
| 11 | .0000E+00 | .0000E+00 |
| 12 | .0000E+00 | .0000E+00 |
| SUM | .1526E-04 | .7629E-05 |
| ABS SUM | .3436E+04 | .2476E+04 |

Thank you for using the demonstration version of the H P E Analysis Module.
For further information on the H P E Analysis Programs contact:

H P E
102 Independence Dr.
Forest, Va. 24551

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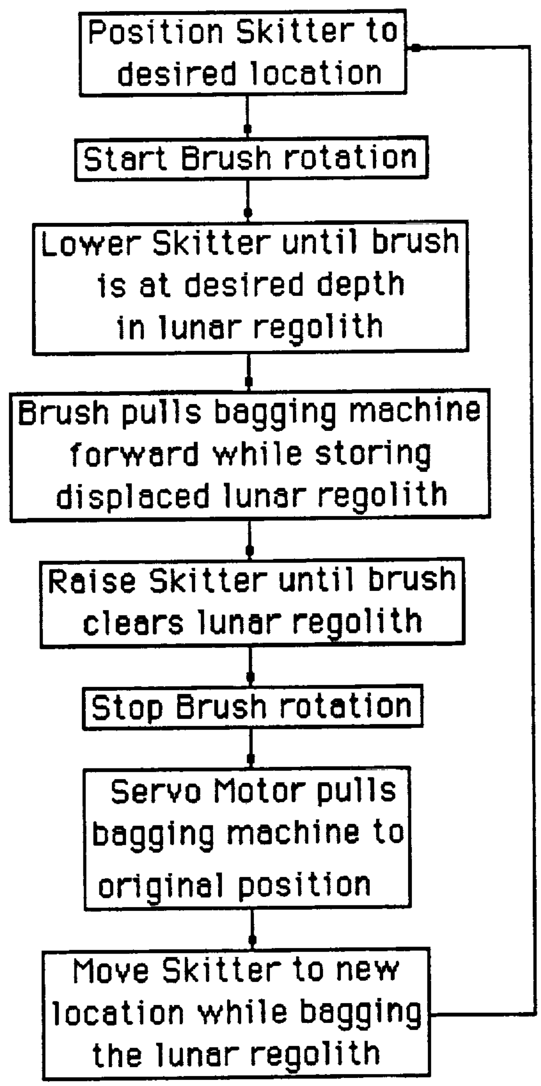
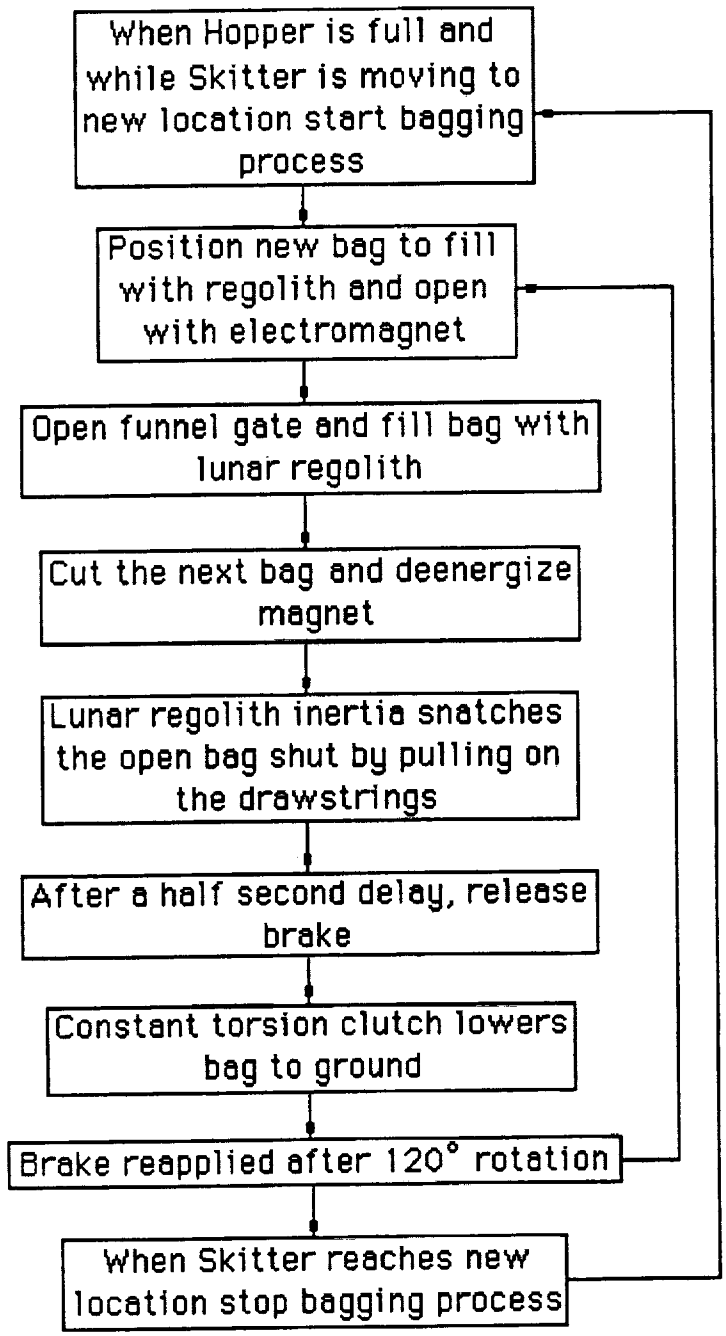
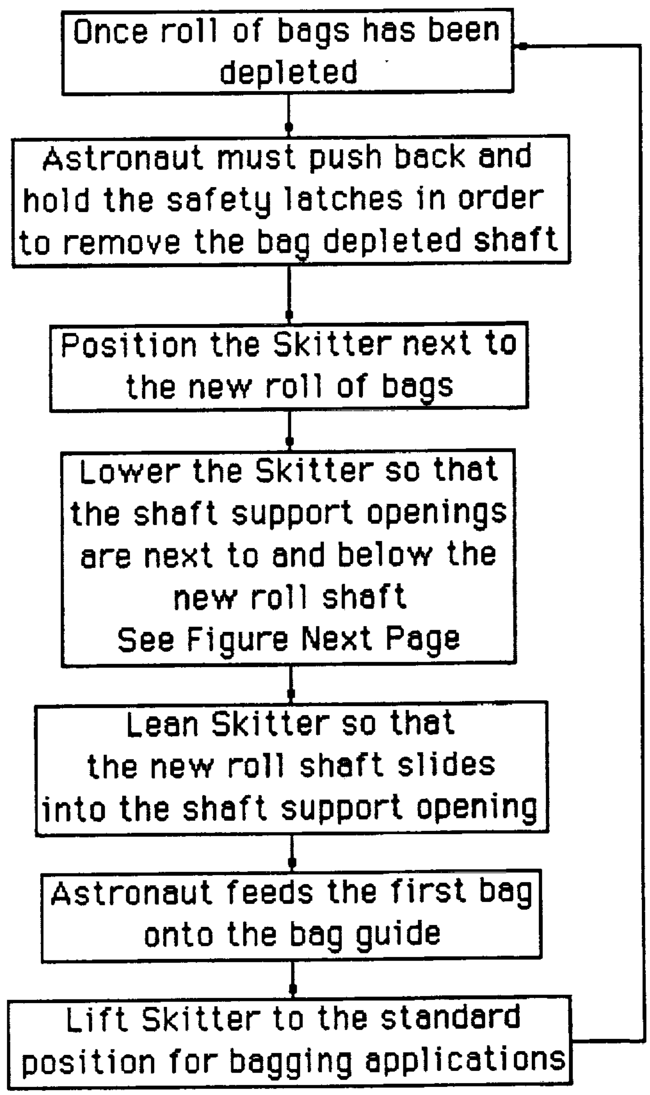
## 1. Brush Movement Flowchart



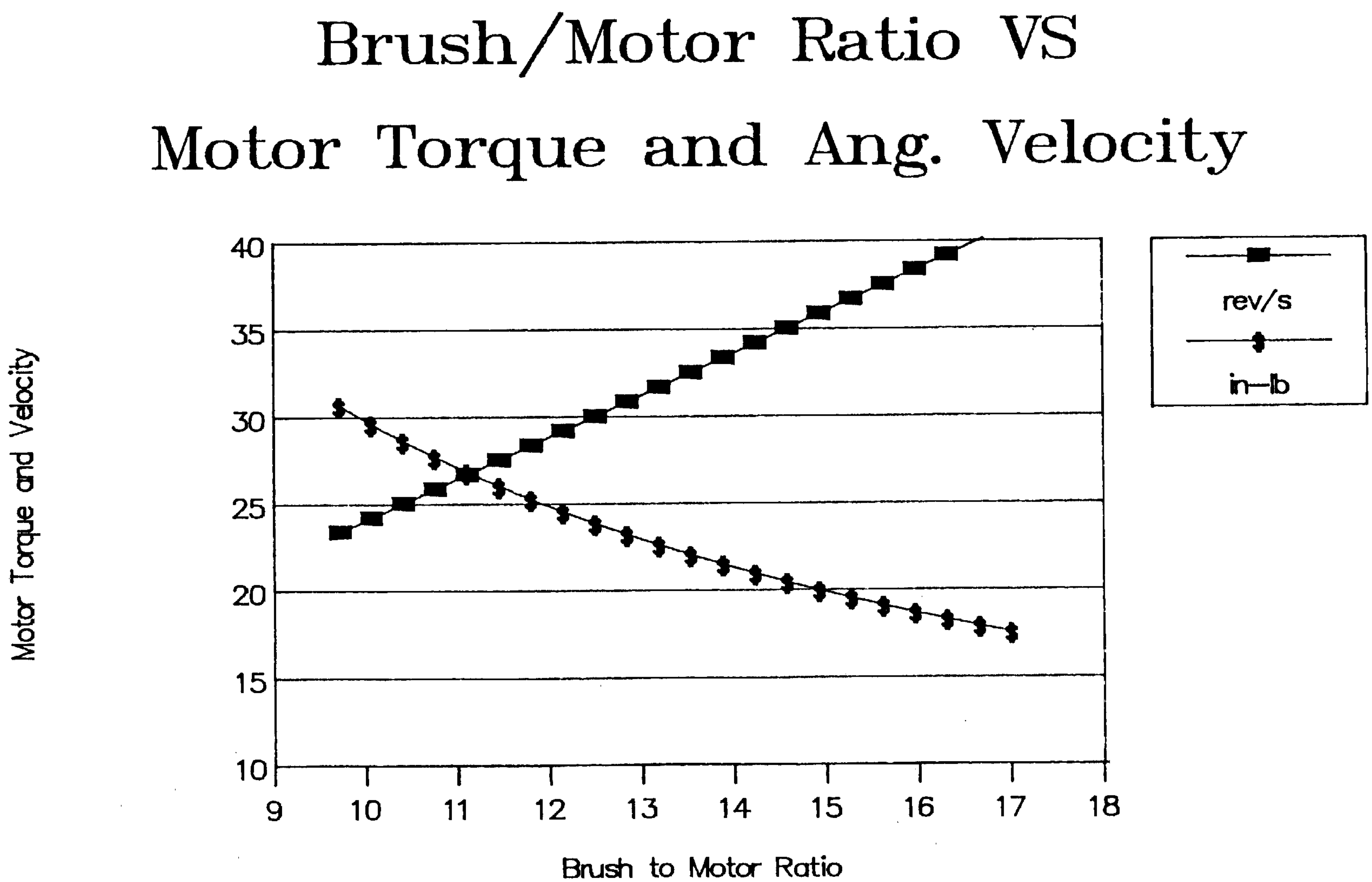
## 2. Flowchart of the Bagging Process



### 3. Flowchart for Replacement of Roll of Bags

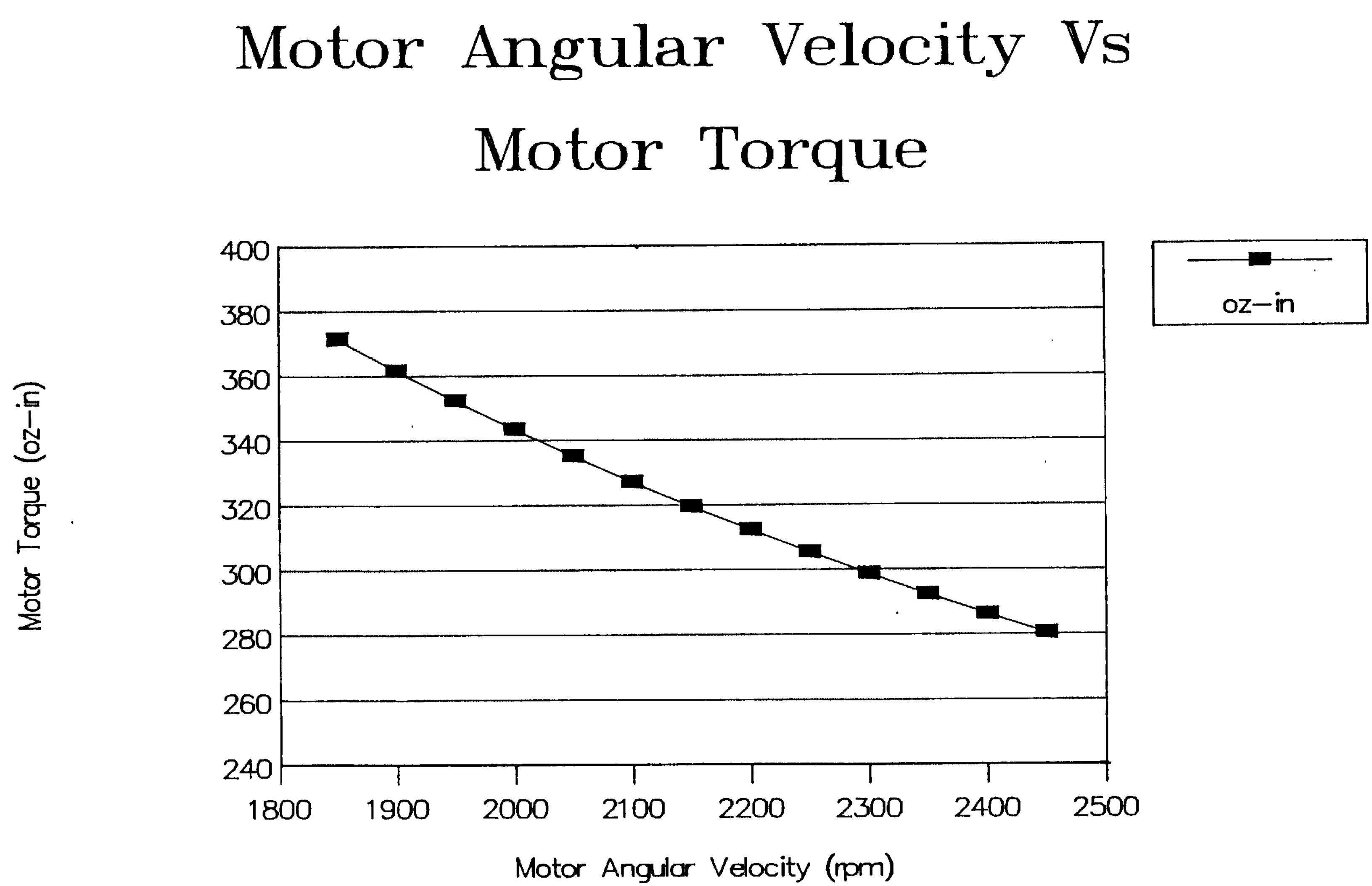


GRAPH I



Brush/Motor Ratio VS
Motor Torque and Ang. Velocity
Motor Torque and Velocity
40
35
30
25
20
15
10
9
10
11
12
13
14
15
16
17
18
Brush to Motor Ratio
rev/s
in-lb

GRAPH 2



Motor Angular Velocity Vs
Motor Torque
400
380
360
340
320
300
280
260
240
1800
1900
2000
2100
2200
2300
2400
2500
Motor Torque (oz–in)
Motor Angular Velocity (rpm)
oz–in

## 5. REFERENCES

Shigely Joseph E., Mischke Charles R., *Mechanical Engineering Design,* McGraw Hill Book Co., New York. pp. 54

McGill David J., King Wilton W., *Engineering Mechanics: Statics,* PWS Publishers, Boston. pp. 351 - 352

Brandrup J., Immergut E. H., *Polymer Handbook,* Interscience publishers, New York. pp. 61 - 93.

Mohr Gilbert J., Rowe William P., *Fiberglass,* Van Nostrand Reinhold Company, London. pp. 241 -265.

Adsit N. R., *Composites for Space Applications,* ASTM Standardization News, December 1983. pp. 21 - 23.

Schrantz Joe, *Coatings Vital for Space Performance,* Industrial Finshing, August 1986, pp. 16 - 18.

Davis John G., Dixon Sidney C., *Beyond Simulation,* Aerospace America, July !988, pp. 38 - 40.

Krempl E., Elzy D., Hog B., *Uniaxial and Biaxial Fatigue Properties of Thin-Walled Composite Tubes,* Journal of the American Helicopter Society, July 1988, pp. 3-10.

VSMF Catalogue Service March - April 1990, *Sweepster Jenkins Equipment Co., Reliance Electric Co., Hilliard Corp.*

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