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AUTOMATED RAISED PAVEMENT MARKER MACHINE (CONVEYER SYSTEM)

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ABSTRACT

This report summarizes a project directed towards the development of an automated machine for placing raised pavement markers. The report includes the basic design criteria established in the project and the various concepts considered to fulfill these objectives. The report also contains the detailed design, construction, testing, and evaluation of the automated Raised Pavement Marker (RPM) Applicator (conveyor belt) System. This machine was designed to apply reflective and non-reflective raised pavement markers with bituminous adhesive from a vehicle traveling up to 10 MPH. The results of this project show that a machine can be manufactured which has the ability to apply raised pavement markers and marker adhesive from a moving vehicle while allowing the operator to remain within the protective confines of the vehicle cab. The automated raised pavement marker machine (RPMM) was able to apply markers with pseudo-bituminous adhesive at speeds up to 5 MPH, making standard marker patterns or placing a single marker. The feasibility of an automated raised pavement marker machine was clearly demonstrated

BACKGROUND

Currently the pavement marker placement process is time consuming and creates a number of safety hazards. A truck with a specially designed carriage moves into position and stops near the marker which is to be placed, a maintenance worker then applies adhesive to the road via a hand held wand and presses the marker into the adhesive by hand. This procedure requires the operator to extend his/her hand and arm near oncoming traffic. The bituminous adhesive is approximately 400° F when applied, so the operator must keep their fingers clear to avoid burns. The slow moving truck requires lane closure and creates traffic congestion, and the start and stop operation imparts significant wear on all the equipment. The University of California, Davis campus (UCD), under contract with the California Department of Transportation (CALTRANS), has developed a raised pavement marker placement machine to automate the marker placement process.

An earlier phase of the automated raised pavement marker project entailed building a machine that could lay markers from a stationary vehicle while an operator directed the position of a marker placement holding an arm attached to the end effector unit of a remote controller. This process speeds up the operation and increases the operator's safety by allowing the operator to keep his hands and arms within the protective area of the vehicle. However, the unit still requires the vehicle to start and stop action similar to the existing operation and was not be able to eliminate the exposure of the operator to the highway traffic and hot adhesive. This phase of the project is to develop a machine which is more automatic and to able to apply markers while the vehicle is in motion.

PROJECT OBJECTIVES

The overall objective of this project is to move the operator into the vehicle cab and apply markers while the vehicle is traveling at speeds up to 10 MPH. This will increase operator safety, minimize traffic hazards and congestion, maximize the efficiency and speed of marker placement. The overall scope of this project was not to produce a "highway ready " rugged machine but to built a proof-of-concept device that would be used to gain interest from equipment manufacturers to invest in the reproduction of this equipment or a modified design similar to this machine utilizing knowledge gained from the research efforts of this project.

The UC Davis/CALTRANS project team has established this set of performance goals for the marker placement machine system.

- The system shall require the use of no more than two operators to perform the driving tasks and operation of all controls.
- Any exterior mounted equipment shall retract into a safe and secure position when not in operation.
- The system shall be easily maintainable and repairable utilizing stock components wherever possible.
- The system shall be designed such that it will provide proper visibility for the driver to insure safe operation.
- All controls for the system shall be located at the operators station or within the vehicle cab.
- The system shall be able to place both types of markers, dots and reflectors presently being used.
- The system shall meet or exceed all California vehicle codes and regulations
- The system shall be self clearing in the event of clogging or jams.
- The system shall operate at a continuous speed of up to 10 miles per hour with a transport speed of 55 miles per hour.

THEORY OF DESIGN

During the initial phase of the project, many design concepts were considered for the automated marker machine, figures i.1-i.7 are sketches which represent some of the various concepts considered. The goal of the second phase of the raised pavement marker project is to increase the operational speed of the marker operation to 10 mph. Again a number of concepts were considered for this phase of the project and the design concepts for the second phase are presented in figures 6-10.

After considering the various concepts and ideas, the project team decided to pursue the machine which was determined to have the best probability in meeting all the goals that were established by the group and seemed to be the most feasible to produce. The concept that the project team chose utilizes conveyor belts to transfer the markers to the road surface (Fig. 7). There are various ideas that our design follows. Each individual sub-system will be thoroughly explained in sections I through VII of this report.

The automated raised pavement marker machine has three main sub-systems. The marker dispensing system (see section I & II), the marker pressing/securing system (see section III), and the adhesive dispensing system (see section IV). All three systems were designed to operate within close proximity to the ground. A belt type system was chosen because it allowed rapid repeat cycling rate for successive marker placement, was relatively inexpensive to construct, and could be synchronized to the roadway mechanically.

One concept used in the design is to keep the marker separate from the adhesive during the process until they are applied to the road surface. This would allow the process to remain as clean as possible without the possibility of adhesive gumming up the mechanical functioning of the marker application device. Another concept used is a mechanical drive/ synchronization system. Our design uses a mechanical chain drive system (see section V) to drive all the belt sub-systems as well as synchronizing the belt speeds with the road surface. This allows the system to operate with relatively little external power supplied, the external power only drives the electronics and trigger the clutch brake systems.

Preliminary tests were conducted to determine how rapidly the required quantity of adhesive could be dispensed to the road surface. The result of these tests indicated that to produce the proper adhesive pattern the downward velocity of the adhesive material must be as slow as possible to prevent splash back. Therefore our design uses gravity to dispense adhesive material.

In order to operate the RPMM at 10 MPH, a marker has to be applied approximately every 250 milliseconds. This requires a very high marker feed rate. Our marker dispensing system is designed with very little friction (see section I) and requires only rotational motion to apply the markers onto the marker delivery belt. Another requirement of the device was the ability to lay markers in various patterns currently used on California Highways (see Appendix E), as well as apply single marker at random for replacement of missing markers on existing lanes. To accomplish this we designed the system with electric clutch/brakes that have the ability to cycle on and off between the individual markers (see section V). This gives the unit the capability of both new lane marking and replacement of missing markers on existing highways. an electronic control system with a programmable micro-controller was developed to implement the sequence and synchronization control(see section VII).

RESULTS AND DISCUSSION

The results of our project show that it is possible to fabricate a device that is capable of applying raised pavement markers to the road surface while a vehicle is traveling continuously. The tests on our actual machine were conducted at speeds up to 5 MPH applying both types of markers and pseudo-bituminous adhesive to the road in two different patterns (Caltrans Standard Pavement Delineation ,Detail 11 & 23. see Appendix E) as well as in a single mode. The final field tests were conducted with the electronic control unit operating automatically while the operator remaining in the vehicle cab. The pseudo-adhesive quantity applied was found sufficient to surround the marker and encapsulate all edges. The deviation of marker placement was approximately ±1.5" at 4-foot intervals. There was no measurable deviation for adhesive application. The alignment of the marker and the adhesive puddle was achieved by adjustment of the electronic controller during the operation without stopping the vehicle.

CONCLUSIONS AND RECOMMENDATIONS

The automated raised pavement marker (convey belt system) has demonstrated the feasibility of automating the process of raised pavement marker placement. The concept of utilizing continuous conveyor belt systems has been proven to be an effective, economical method of automatically applying raised pavement marker to the highway.

Recommendations for future developments include the transfer of this technology to commercial or government entitles to further develop the unit into a "highway ready" machine that is rugged, reliable without jams or missing markers. It is suggested that the development of such machine be in close conjunction with an RPM sensing system. There are various alterations and modifications that the project team recommends in the subsequent designs. These recommendations are discussed in the individual sections that explain in detail the operation, design and results of each sub-system.

SECTION I

MARKER LOADER SYSTEM

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Summary

A Marker Loader System (MLS) featuring a starwheel mechanism has been designed and constructed and its performance tested on the automated marker pavement machine. The results showed that this new loading system, coupled with a wrap spring clutch/brake was capable of loading markers continuously or at random from a vehicle traveling up to 5 mph. The concept of the starwheel mechanism, which employs rotational motion with minimum friction and loads marker vertically via gravity, was well proved. The principles and critical parameters in design of the starwheel mechanism are identified and presented in the report. The results suggested that the starwheel or its concept could be adopted in other applications such as a singulator or an intermittent feeder.

INTRODUCTION

The functions of the marker loader system are to store a number of markers and to load them one at a time on to the marker delivery system. The main requirements are as follows:

1) Be able to load both square-shaped reflectors (type C, D, G and H) and round ceramic dots (type A and AY) according to Caltrans standard.

2) Be able to load markers within 270 millisecond time interval when the automated pavement marker machine is operating in a continuous mode at required design speed (10 mph).

3) Start and stop rapidly and accurately to assure synchronization with the other subsystems.

In order to implement the functions defined previously, the marker loader has to consist of two functional components, i.e., storage and loading mechanisms, with the latter as a key contributor. Three design concepts of loading mechanisms were considered and analyzed.

Design Concept 1

Fig. 1.1 illustrates the first preliminary design concept which applies an oscillating motion. The markers are stored in an inclined magazine and are held by a guide wheel and sliding stops. A rocker driven by an air cylinder makes two sliding stops, the pin of which can slide in the slots on the rocker, moving up and down in the opposite direction. In the ready state, sliding stop 1 moves down and sliding stop 2 moves up by returning of the air cylinder such that the first marker is pushed down along the chute and the other markers in the magazine are blocked by sliding stop 2. Two stops reverse the direction during cylinder extension and the marker stack moves down until hit sliding stop 1.

This mechanism needs only a small driving force since markers are moved mainly by gravity and it is compact. However, it is sensitive to quite a few parameters such as the height of the slide stops, the position of the guide wheel, the tolerance of markers and the angle of the magazine, etc. Furthermore, it is difficult to tune the mechanism for reliable operation at a very high marker feeding rate.

Design Concept 2

The second design concept applies a reciprocating motion. As shown in Fig. 1.2, the markers are stored in a vertical magazine and held by two angle bars on both sides at the bottom of the stack. While loading, the bottom marker was pushed off the stack by a slide driven by an air cylinder. Then the marker dropped on to the delivery belt which was moving at the direction 90 degree to the sliding motion.

Compared to design concept 1, it is simple and compact. However, the mechanism requires a relatively large driving force to overcome friction in order to push the bottom marker laterally off the whole stack. Furthermore, the reciprocating motion limits the loading speed which may result in failure of meeting the design requirements.

This design concept was detailed and developed on the pavement marker phase I. The test evidence and previous analysis showed that a 90° sudden direction change at high speeds caused marker motion disturbance and noise resulting from impact.

Design Concept 3

As shown in Fig. 1.3, the third design concept employs a rotational motion. A stack of markers stored in a vertical magazine and supported by two star wheels. When the starwheels turn, the bottom marker is released and drops on to the delivery belt by gravity. This mechanism feeds markers vertically and efficiently with minimum friction. It is very simple, compact and only needs small driving force.

Among the three, the starwheel mechanism was considered most feasible and favorable in meeting design criteria of smooth loading at rapid cycling rate, however, the determination of the dimensions of the starwheels is critical and the motion control was a challenge.

DESIGN FEATURES

System Description

The marker loader system consists of two units of marker loaders, one for the squared reflective markers and the other the ceramic round dots. Each unit is composed of (see Fig. 1.4): 1) a vertical storage unit holding a stack of markers; 2) two starwheels which support the whole stack and load the markers each at a time discretely as desired; 3) a wrap spring clutch/brake which controls intermittent motion of starwheels; 4) a pair of gears which ensure two starwheels, when triggered, rotate in the opposite direction synchronously. Two loading units are driven by an electric motor with a speed control through a gear drive.

Storage Units

Two storage units were designed, one for reflectors and the other for round dots. Each unit can hold a stack up to 70 markers so that the field test can be conducted for a reasonably long operating distance (280 yards) in a continuous mode without refilling. The unit was designed such that, while achieving smooth marker descending, the clearances between markers and inner wall of the units were minimized so that the starwheels can function properly. Each unit was composed of an upper canister and a lower hopper, which were bolted to each other then mounted on the main frame aligning with the starwheel set underneath.

For simplicity in fabrication and ease in filling of markers, the upper canister was structured as a "wire frame" welded with four 3/4" x 3/4" x 1/8" sharp corner aluminum angle bars and two 1-1/2" x 1/8" aluminum bars. Sharp corner was considered an important feature for it made small clearance between markers and inner wall possible. Aluminum was chosen for it was the only availability in stock featured sharp corner. The elimination of painting or rusty layer due to its high corrosion resistance also made the clearance easy to control. The 3/4" x 3/4' angle bars made a wide opening between bars for convenient and comfortable hand filling while remaining satisfied stiffness of the whole canister. The height of the canisters were 50". The dimension of the inner wall was 4.25" x 4.25" for reflectors and 3.5 x 3.5" for the dots.

Starwheel design

In design of the starwheels, the following consideration have to be taken into:

1) Each pair of the starwheels must be reliable to support the entire stack of 70 markers which weighs 35 lb.

2) Allow no motion interference between starwheels and markers.

Unit Description

To simplify the structure and fabrication of the starwheel, a set of paralleled rods was used as star tips instead of a several sets of radial fingers as proposed in the primary design (refer to design concept 3 in Fig. 1.3). The rods were assembled on two plates by inserting the two ends into equally distributed holes on the plates. Nylon bushings were provided to permit each rod to rotate about its axis so as to reduce friction and wearing during marker loading process. The starwheel unit was driven by the shaft through the keys between the shaft and the plates.

Dimension Determination

The parameters to be determined were: the distance between the supporting point to the edge of the marker S (refer to Fig. 1.4); rod diameter d; the pitch diameter of the starwheel D and the number of the rods N. The supporting distance S was pre-selected such that a reliable support to the stack of the marker can be provided without causing significant difficulties in achieving a smooth motion of the starwheel-marker system. Since the tolerance of the markers is ±0.125", the supporting distance S was considered not to be less than 0.25". Preliminary graphic analysis indicated that slight increase of S would cause significant difficulties in obtaining a smooth motion of the starwheel system. Therefore the distance S was selected 0.25".

Diameter of rods d was considered not to be less than 0.25" for strength and stiffness as well as for structural reasons. Graphic analysis also showed that larger diameter increased probability of motion interference, therefore d was chosen 0.25" and 0.313" for computer simulation test. The number of the rods were selected to be 4, 6, and 8.

To ensure no motion interference between the markers and the starwheels, the distance between adjacent rods must not exceed the height of the marker . Therefore the pitch diameter of the starwheel must satisfy the following equation: $D = 2R \geq H / \sin(3.14 / n)$, where H is the height of the marker which is 0.75" and n is the number of the rods. The restriction on the pitch radius can be thus established for the selected rod number n, i.e., R_{max} = 0.53" when n = 4; R_{max} = 0.75" when n = 6; R_{max} = 0.98" when n = 8. In addition to the above constraint, three clearances must be acquired. First, the rod has to engage into the marker stack smoothly without jam, i.e., a clearance $\Delta 1$ (Fig. 1.6) between the rod surface and the bottom of the marker is required. This clearance should be minimized during loading process so that the impact of the whole stack of the markers on the rods at each load can be reduced. Secondly, there must be a clearance between face surface of the marker and the rod surface $\Delta 2$ or the starwheel will fail to turn because of interference. Furthermore, the marker has to be disengaged from the starwheels and released onto the delivery belt freely, i.e., there should be a clearance $\Delta 3$, between the surface of the rod and the edge of the marker. This clearance should be greater than half of the tolerance of the marker width so that the largest marker can be released freely, i.e., $\Delta 3 > 0.0625$".

Parameters selected based on these considerations are shown in Table 1.1. The starwheel motion with various parameter groups was simulated on computer and analyzed. The optimum dimensions were determined as: R = 0.725", d = 0.313", n = 6 resulting in $\Delta 1$ = 0.06", $\Delta 2$ = 0.25" and $\Delta 3$ = 0.09".

Modification for Round Dots

The starwheel thus designed was based on the geometry of squared reflectors. It was also suitable for the round dots whose dimension were controlled H=0.75" and h=0.125", where H is the height of the dot and h is the height of the cylindrical part. However, the dot height varies from 0.63" to 0.80" according to Caltrans standard. For those dots with the height less than the pitch diameter of the starwheel i.e., $H \leq 0.725$, the requirement of the maximum pitch diameter was violated. Furthermore, though the cylindrical height was standardized to be 0.12±0.05", the actual dimension is far out of the range. The h of the dots used in the tests varied from 0.25" to 0.375". As a geometric result, the arc face surface of the dot was "popped" up, leaving no clearance (Δ3) to the rod surface to it. This violates the requirement of clearance Δ2 and will create a dead jam. In order to make the designed starwheel adaptable to these round dots, a modification was made by taking the nylon bushings out of the holes. Thus, with a total clearance of 0.125" between the rod end and the plate hole, the rod can be pushed down by dot weight or lifted up by dot's face surface. As illustrated in Fig. 1.6, clearances Δ1 and Δ2 were obtained.

The starwheel shafts were made of 0.5" stock cold rolled rod. A 7/8" x 1/2" sleeve was added to each shaft to limit the lateral deviation of the marker while sitting on the starwheel rods. The mount height of the starwheel shafts from the delivery belt was calculated to be 2.125" leaving a minimum 0.5" Clearance between rods and the on-belt marker to ensure the marker a smooth moving while confining its upward bouncing.

Drive Train for Marker Loading System

Since the marker loading system is to load markers within certain time intervals (e.g. 270 milliseconds when vehicle at 10 mph) as desired, it is not necessary to keep the loading system completely synchronized with the vehicle and the other systems. In order to simplify design and shorten the drive train, a separate drive was designed instead of taking power from the wheels of the marker machine. As shown in Fig. 1.7, the drive train includes: an electric motor with a speed control; a gear drive of four gears; two wrap spring clutch/brakes, and two sets of starwheel gears. Two driving starwheels are driven by the gear motor through a group of four gears. Another two pairs of equal sized gears drive the driven starwheels which rotate in the opposite direction of the driving ones. The motion of each pair of the starwheels is controlled by a wrap spring clutch/brake which is mounted on the shaft of the driving starwheel.

Selection of Clutch/Brake

The intermittent motion of the starwheels is implemented by a clutch/brake unit, hence selecting the clutch/brake is of essential importance in the design of the drive train for the MLS. In order to keep right timing with the whole machine operating at 10 mph, the clutch/brake has to meet the following requirements:

1) Rapid start-stop cycling rate, up to 240 cycle/min.;
2) Six stops per revolution;
3) Accurate and repeatable positioning;
4) compact to fit in the limited space on the machine.

Wrap spring clutch/brake unit from Warner Electric was selected for its unique features and low cost. The solenoid actuated clutch/brake package can start and stop within ±1/2° per revolution accuracy with no cumulative error at cycle rates up to 1200/min. Its overall dimension is within 4-5/8 x 4-3/8 x 2-5/8". Size CB-5 was determined based on the total torque requirement and verified by unit inertia. The minimum inertia requirement was also checked to ensure that the clutch/brake accuracy capacity of ±1/2° be achieved (see appendix C for calculation).

Two wrap spring clutch/brakes are identical except the rotation is opposite. Both are with 24 DC standard coil voltage, 1/2" standard bore size and a six-stop collar.

Motor and Gear Drives

Since torque load is not a significant factor in the marker loading system, the speed requirements were the main concern, which were:

1) To achieve the capacity of loading markers within a 270 millisecond second time interval, the speed of the starwheel with six stops had to be greater than 37 rpm.

2) The preferred minimum speed of the wrap spring clutch/brake unit was 50 rpm to ensure a satisfied performance for rapid and accurate start/ stop cycling.

3) It is desirable that the motor speed is adjustable for testing a new starwheel loading system.

Taking additional considerations such as space restriction and mounting position into account, a 90 v permanent magnet DC gear motor model 4Z133 from Dayton was selected. A remote mount gear motor speed control was equipped which converted 115 v AC from common power supply to 90 v DC and provided on/off continuous speed adjustment.

The clutch/brake gear drive consists of four gears, a driving gear mounted on the motor output shaft, two driven gears on the input flanges of the clutch/brakes and a fourth intermediate gear was added to reverse the rotation of the clutch/brake for round dots. Gears were 10 DP, 0.5" face and made of nylon. Nylon was chosen in this open gear drive (without gearbox) because of its corrosion and impact resistance, self-lubricating and quiet performance. Four equal sized starwheel gears were determined based on the starwheel design. 10 DP with 48 teeth were found best fitting the shafts' distance from standard gear in stock. Since the wrap spring clutch/brake features "the higher the load, the tighter the spring wraps down", steel gears were used rather than nylon ones used for the rest of gear drives on the marker machine to increase load inertia and torque so a better performance can be obtained.

TEST RESULTS AND DISCUSSION

The marker loader system was tested both in the lab and on road. Prior to the completion of the electric control system, the tests were all conducted manually. The solenoids of two wrap spring clutch/brakes were triggered by pushing buttons with our finger so as to start the starwheels. Motor speed was set at 0.5 of the full speed according to the finger responding capacity. during the final field tests, the motion of the starwheels was controlled by the electronic unit and the marker loader system fed two kinds of markers according to the previously programmed pattern or the single marker command. The motor speed was then set at 0.8 to properly match the timing of the micro-controller.

During tests, the wrap spring clutch/brakes, the motor and the starwheel functioned well especially when controlled by the electronic control unit and the marker loader system was capable of loading both reflectors and dots continuously and randomly at the vehicle speed up to 5 mph. When operated manually by a skillful operator (button pusher), the system loaded markers forming complete lines in a 48 foot pattern (Caltrans detail 13) for 350 yards and in a 24 foot pattern (Caltrans detail 23) for 250 feet repeatedly with only one or two misloadings. Controlled by the electronic unit, the system loaded markers making pavement delineation in the pattern of Caltrans detail 13 repeatedly with a few mistakes.

Jam occurred during tests in several cases. When the clutch/brake trigger button was held by the finger too long, two stops of the stop collar passed before the clutch actuator was released and two markers were loaded causing jam on the delivery belt. Jam also happened underneath the starwheels when the marker was loaded right on the cleats. These two jamming cases were mainly because of limitation of human response (finger and eyes) capacity and were reduced by practicing. With electronic control, these types of jam was eliminated. The "cleat" jam could be eliminated by raising the starwheel up to adjust its clearance to the belt surface.

Double (two) reflector loading was observed even when the button was pushed properly. If the first reflector failed to be released completely from the starwheels at the releasing position, it will be loaded with the next one when the second trigger was fired. Double loading caused consequent jamming right underneath the starwheels or at the entrance between two timing belts. Improperly assembling of the starwheels was one of the causes of this kind of jam. The problem was partially resolved by adjusting the starting position of the starwheels as designed. Other sources of the trouble were relative large hopper clearance and high side opening of the hopper above the starwheels. The side opening was designed high to leave space for upward adjustment of the starwheel for increasing the clearance from the belt in case needed for a smooth marker motion on the belt. However the high side opening left freedom for marker to deviate from the center of the starwheel pair and occasionally caused jam with both round dots and reflectors. The actuator of the clutch/brake for reflector was found weaker than the other one, which might also cause double marker loading.

CONCLUSIONS AND RECOMMENDATIONS

The marker loader system developed is a simple, compact and efficient unit. The results showed that the system was capable of loading markers at required high feeding rate continuously and randomly. The concept of the starwheel, which applies rotational motion with minimum friction and loads markers via its gravity, was well proved. It is suggested that the starwheel mechanism or its concept could possibly be employed in some other applications such as a singulator or an intermittent feeder. However, to make it a trouble free system, improvement needs to be made. Since the parameters such as supporting distance S and clearance $\Delta 3$ are relatively small and sensitive, a better control of the marker position on the starwheels is desired. This can be achieved by reducing the hopper size to decrease the wall clearance, lowering hopper side opening and increasing sleeve diameter. In contradictory to small S and Δs the hoppers and bolt holes are all roughly made. To free the jamming trouble, precision of fabrication and assembly has to be improved. An automatic marker patch filing storage has been suggested for road operation. Column packaging of markers directly from the manufacture would certainly benefit this filling process.

SECTION II

MARKER DELIVERY SYSTEM

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Summary

A timing belt based marker delivery system has been designed and tested. All the elements designed for controlling marker motion functioned properly. Final marker placement was achieved via gravity with acceptable deviation. The results of field tests showed that the performance of the system was reliable and stable, and the overall design requirements were met. It is with little doubt that the marker delivery system is capable of laying markers at 10 mph both for new highway construction and for existing road maintenance.

INTRODUCTION

The function of the Marker Dispensing System is to convey the raised pavement markers to the road surface at a required speed. A belt system was chosen during the overall design of the marker machine because its continuous motion allows a rapid cycling rate for the successive marker placement. The design criteria of the system are as follows:

1) The system should be able to deliver markers every four feet with one inch tolerance (i.e., 4'±1") in a continuous mode.

2) Marker motion should be synchronized with the vehicle and road surface.

3) Marker breakage should be minimized.

DESIGN FEATURES

System Description

The main components of the marker delivery system, as shown in Fig. 2.1, include: 1) a profiled timing belt with two sets of equal spaced cleats and three associate pulleys; 2) a frame incorporating a horizontal and inclined frames at the pivot; 3) marker motion constrainers including a stopper, a deflector, a restrainer and four walls; 4) a chute and 5) a belt tensioner. The whole system is suspended under the main frame of the Raised pavement marker machine through four tabs with bolts.

Being loaded from the marker loading system to the horizontal part of the belt, the marker is carried and moved at belt speed via friction. The marker then is forced to change the direction at the turning point by the deflector and continues moving on the inclined belt surface. This motion is interrupted by the rubber stopper and the marker is held until the profiles (cleats) approaches and pushes it through the stopper. The marker is then transferred to the chute from the belt and finally is laid on the road at the velocity whose horizontal component is zero relative to the ground. The walls are designed to limit the lateral movement of the marker so as to reduce its deviation off the pavement line. The upward bouncing of the marker is confined by the deflector, the restrainer and the press belt.

Belt and Pulleys

Since the marker delivery system functions both as a marker conveyor and a marker placer, the delivery belt was configured in such way that its horizontal portion receives markers from the marker loading mechanism smoothly while its inclined portion delivers markers all the way down to the road surface through the chute. The main design parameters need to be determined are the slope of the inclined portion of the belt, the length of the belt and the proportion of the horizontal and the inclined portions.

The slope of the inclined belt portion was first determined. The vertical component of the belt velocity causes impact of the marker on the ground resulting in marker breakage. And this component increases with the belt slope. The preliminary test proved that the slope had significant effect on the marker breakage. Therefore a small slope was desirable in view of reducing the marker breakage. However, in order to locate the adhesive dispenser underneath the delivery belt, the slope can not be too small. Taking account of both considerations, a compromise of a 30 degree slope was selected.

Based on the overall machine consideration, it was determined that two markers would be laid down in each belt revolution. To provide the marker leaving from a belt with 30° slope a zero relative velocity to the road surface, the belt velocity should be 17 fps and the length of the belt with two profiles was calculated to be 111 inches. A timing belt was used in this application to eliminated the slippage for synchronization purpose. A polyurethane belt of 1/2" pitch, 3" width and 111" length with two equal spaced profiles and three matching pulleys were fabricated by Breco-Flex Corp. Each profile was split into two cleats 1.5 inches apart to leave a space to the take-up wheel . The cross section of the cleats is 3/4" x 3/4" x 1/2" which was a compromise of cleat strength and the stress concentration of the belt caused by a narrow take-up wheel. Three inch width was chosen instead of 4" (marker width) to reduce the cost as well as the frame width. Three pulleys were all 1/2" pitch and 35 tooth. aluminum was selected for its light weight so the torque load and heat dissipation of the electric clutch/brake drive could be reduced.

In proportioning the belt into the horizontal portion and the inclined portion, the following considerations had to be taken: 1) The length of the horizontal part should permit the belt to receive different kinds of markers from two starwheel loading mechanisms and allow the round dots to accelerate to a stable velocity before it was deflected. 2) This length should be minimized so that, with a predetermined belt length of 111 inches, the delivery belt could have adequate height for the adhesive dispenser to be installed underneath it. A compromise solution of 25" for the horizontal portion and 22" for the inclined portion resulted in the frame height of 11" with a predetermined belt-ground clearance of 2".

Frame

An independent frame was designed so the delivery system could be a separate unit. The frame serves as a base to hold the pulleys and mount all other accessories such as the take-up wheel, the walls, the stopper, etc.. The frame was composed of two sub-frames, i.e., the horizontal and inclined frames according to the configuration of the belt system. The inclined frame could pivot about the axis of the idle pulley through the bearings and the shaft. The bearings were housed in the bore of the pulley. The shaft, in turn, was supported by the horizontal frame but fastened to the inclined frame at its end. When the main frame of the pavement machine was adjusted around its joint by the turnbuckle, the tilted frame could pivot accordingly so proper gear mesh could be remained.

The frames were welded with 2" x 1" x 1/8" rectangular tubing, the same material used for the sub-frames of the main frame. The lengths of the frames were determined based on the belt configuration and proportion. Both frames have the same width which was determined such that, while leaving enough room to screw the walls to confront four inch wide markers on both sides, the width of the frames should be minimized so the overall width of the machine could be reduced accordingly. Each frame was extended by welding two 2 x 1/4" bars on both sides to form the pivot. Two 1-1/2 x 1/4" bars were welded on the other end of the inclined frame to serve the bases to mount the pillow blocks for the driving pulley.

Chute

In order to maintain the marker synchronized with the ground after it leaves the delivery belt at the height of 8", it is important that the motion of the marker in this last stage be well controlled rather than a free fall with its initial velocity of 17 feet per second at 30°. A chute was designed to serve this purpose as well as to reduce the marker breakage by lower the drop height from 8" to 1" and change the motion direction of the marker from 30° to 5°. The chute was made of 1/8" thick plate bent at both sides to form 1-1/2" high walls The front part of the chute was warped up by 25° resulting in 5° slope to the ground. This slope change would reduce the marker velocity accelerated by its own gravity while sliding down on the smooth metal surface after leaving the belt. It would also reduce the vertical velocity component which caused impact. As a result, the marker breakage could be decreased. The chute was attached on a bracket through slots with screws. The U shaped bracket, in turn, was mounted on the posts of the main frame through slots with bolts. Those slots would permit the chute of adjustments both longitudinally and vertically during the test and the operation. In compensation for these adjustments, a trough was added to provide markers a smooth transition from the belt to the chute. The trough was also made of 1/8" thick plate with 1-1/2" high walls. It was riveted loosely on the walls of the inclined frame do it could pivot around to keep its end being contacted with the chute whose position was adjustable.

Stopper

The function of the stopper was to ensure that the synchronizing element (cleats) could work effectively so that the marker could be laid at exact four foot interval. The stopper should be able to stop and hold a marker carried by the belt but give the marker admission to travel when the cleats contact the marker. The stopper was considered to be a spring-damping element whose spring constant had to meet the following requirements: 1) At small deformation, the spring force must be greater than the friction force between the marker and the belt. 2) When the deformation, in terms of the clearance between the belt and the tip of the spring, was equal or greater than the marker height, the spring force must be such that its component along the belt is less than the pushing force of the cleats, or more precisely, less than the shear strength of the cleats. A piece of rubber was considered an ideal solution for several reasons. Besides its simplicity in design, it is quiet when stopping markers for rubber is a natural acoustic absorber. Furthermore, it is also a natural damping element so that the after-vibration would be eliminated. Since the engineering data was not available, the dimension of the rubber bars was determined by trial and error with the rubber bars available in the shop. A 1/2"x1.5"x5" rubber bar was attached on the bracket bolted on two posts erected from the inclined frame. The rubber bar was backed by a 2" x 3" x 1/8" steel bar which could slide along the rubber vertically thus to adjust the spring constant of the stopper. The stopper could be adjusted in the direction perpendicular to the belt surface as well as the inclined angle to the belt. The stopper was positioned in the region where the marker, being deflected by the deflector, had reached its steady state along with the belt but before entered the channel formed by the press belt and the delivery belt.

Other Features

The Walls

The walls are made of 1/16" sheet metal and equipped along the belt all way along the marker travel path on the belt. They are screwed to the 1"x 1/8" steel bars welded on the frames through the slots permitting the clearance adjustment between the markers and the walls.

The deflector and the constrainer

The deflector was made of a 2" x 1/8" steel bar curved to 150° and was mounted above and parallel to the belts. Attention was focused on the positioning so as to ensure that when hitting the deflector the marker would neither bounce back to the horizontal surface nor turn over on the inclined surface so that a successful and smooth marker deflection could be achieved. The mount height and the curvature of the deflector were graphically determined on the computer by simulating marker motion and finally adjusted by testing during fabrication process. The deflector was extended down to the stopper to serve as a constrainer to limit the marker upward bouncing. A second L shaped 2 x 1/8" steel bar was added in the region between the stopper and the press belt.

The tensioner

The function of the tensioner was to tense the belt as well as to make space underneath the belt available for the adhesive dispenser. However, since this pushing-up was limited by the idle pulley, further tension was accomplished by adjusting both the pillow blocks and their base plates of the driven pulley. A readily available 1 1/8"x4"wheel was chosen as the take up wheel. The wheel was screw adjustable.

TEST RESULTS AND DISCUSSION

The marker delivery system was tested on the road at a vehicle speed up to 5 mph. As observed during the tests, the belt ran smoothly, the stopper, the cleats and deflectors all functioned well. The marker motion was controlled in the way it was designed. The marker spacing was adjusted by turning the variable transmission control knob which changes the drive ratio and thus the belt speed. The average deviation of the marker spacing was measured to be ±1.5 in" at 4 foot interval. The angular displacement was observed and considered acceptable. The marker breakage was not noticeable in the final test though it occurred at the very beginning of the field tests when the chute slope was 30° and the clearance of the chute to the ground surface exceeded two inches.

Marker jams were encountered during the tests. In addition to the jam caused by double-marker feeding due to long button holding as discussed in Section I, jams were also caused by upward bouncing of markers. When a marker moving at 10 fps on the belt with 30° slope was suddenly stopped by the stopper, although the front edge was decelerated to zero velocity, the inertia of the marker mass tended to keep it moving. As result, the tail of the marker bounced up. If this occurred just about the time the cleats were coming, the cleats would penetrate underneath the marker, and pass through the stopper, leaving the marker behind. When the next marker was loaded on the belt, the cleats had to push two at the same time causing jams at the narrow entrance between the press pulley and the driving pulley of the delivery belt. This kind of jam happened most often to the round dots for they had larger mass (0.5 lb compared to 0.43 lb for reflector), and so as inertia.

The jam also caused cleat wearing at the leading edges. Though the extension part was designed to confine the marker from upward bouncing, its downward adjustment was limited by walls. A 1/2" thick rubber strip was screwed on the bottom of the deflector near the stopper to reduce the vertical space above the belt from 1.25" to 0.75" so that upward bouncing was eliminated. And this kind of jam problem was completely solved.

CONCLUSIONS AND RECOMMENDATIONS

The results of the field tests indicated that the belt system is a simple and reliable marker delivery system. Marker motion was successfully controlled by simple mechanical elements and finally placement was achieved via marker gravity. The system appeared to be capable to lay markers at 10 mph both for new construction and existing pave line maintenance.

Modification of the chute is suggested to better control the marker motion so the variation of marker spacing and the rotation of the reflective marker can be improved. The deviation of marker spacing can be further reduced by finer turning of PIV and elimination of electric clutch/brake slippage caused by marker jamming. The mount height of delivery system can be increased one to two inches by re-proportioning the horizontal and inclined portions of the belt to provide more space for the adhesive heating system.

SECTION III

MARKER PRESS SYSTEM

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Summary

A roller-belt system for securing markers on the road has been designed, constructed and tested. Gravity was employed through a rolling weight block to press markers down. And a timing belt was applied to achieve synchronization. The results of field tests show that the marker press system secures markers adhering to the road with little drift. The unit is simple, reliable and easy to maintain. It is believed that the system is capable of operating at much higher speed than was tested.

INTRODUCTION

Firming is the last stage of the marker pavement process. Having dropped on the adhesive puddle from the chute, the marker has to be secured and pressed so as to reduce marker drift and increase its adhesion to the road surface. To serve this purpose, the following requirements has to be met:

1) A sufficient normal force has to be applied on the marker for an effective time period to ensure good road contact.

2) The force applicator should remain synchronized with the ground, so that the marker on the bitumen puddle could be secured with little drift.

A preliminary test was conducted to determine the normal force required. The results suggested that a total force 30 lbs was preferred in terms of obtaining a thin adhesive layer of 3/32" - 1/8". Gravity was considered the simplest solution of applying such a normal force on the marker without involvement of hydraulic or pneumatic systems which are commonly employed in conventional automated machines. In conjunction with the marker delivery system, a timing belt is also used as a synchronizing measure.

DESIGN FEATURES

System Description

As shown in Fig. 3.1, the marker press system is composed of a timing belt drive, a roller press and a spring loaded tensioner. A 3-foot long roller press is positioned inside the belt loop and sitting on the belt which is moving at the vehicle speed backward. The roller assembly is suspended, through slots, on the posts hanging down from the main frame. The clearance of the belt surface to the ground was controlled at 1/2" - 5/8" which is less than the height of the marker. After a marker is applied on the bitumen it "penetrates" underneath the belt and lifts the roller press to force it to float up . The weight of the roller press is thus applied on the marker.

Roller Press and Belt

The roller press is basically a 3"x 3" C channel welded from 3/8" steel plates. on which a series of rollers were mounted 3" apart in parallel. The 3 foot overall contact length provides a 200 millisecond press process at a vehicle speed of 10 mph which we assumed to be sufficient to firm the marker on the road while not to adding unnecessary length to the overall pavement machine. Three identical pulleys, the same as used in the delivery system (1/2" pitch and 35 tooth aluminum) were used. The leading portion of the belt has the same slope as the delivery belt and the chute (30°) and was placed above them so that the motion of the marker can be controlled. A 1/2" pitch, 3" wide and 140" long polyurethane timing belt was configured by pulleys which were supported by the pillow blocks mounted on the posts from the main frame, and was aligned with the delivery belt and the adhesive dispensing belt.

Tensioner

A spring loaded tension mechanism designed for this long span belt drive was positioned inside the belt loop and pushed the belt outward to avoid interference with the wheel axle. A timing pulley was mounted, through its shaft, on two elbow bars. Each elbow bar was loaded by a tension spring on the other end. The tension mechanism was designed such that the force arm decreased as the spring deformation increased. In result, the belt tension could remain relatively constant during its automatic adjusting.

Since the engineering data of the belt was not available from the manufacture, a pair of springs was selected from what were available in the Caltrans shop. The tension was later measured to be 30 lbs which was considered reasonable.

Adjustment

The adjustment of belt-ground clearance could be made by changing spaces between the C channel frame and its brackets. The clearance between the press belt and the delivery belt, which was designed to be 1", can be adjusted by adjusting the pillow blocks supporting these pulleys. Checking this clearance every time when the main frame is adjusted will avoid marker jamming or unnecessary friction increase.

TEST RESULTS AND DISCUSSIONS

During the tests, the system ran smoothly. The tensioner worked satisfactory and the rollers functioned effectively. In a continuous 4-foot interval pattern, the deviation of the marker from the center of bitumen lump was acceptable which indicated that markers were secured during the press process with no obvious drift. After-drift (i.e., drifting after the marker was released from the press belt) was not noticeable during pseudo-bitumen test. The rear main frame was lifted when the rear pulley passed over the marker, resulting in shock and noise. This was because the posts for the rear pulley was fabricated 1-5/8" longer than designed so the clearance of the pulley to the ground was only 1/2" when the frame was adjusted parallel.

CONCLUSIONS AND RECOMMENDATIONS

One conclusion that may be drawn from the result is that the force and the time applied by the press system was sufficient to firm the marker adhering to the road surface. Since pseudo bitumen used in the field test was less viscous, it can be predicted a better result could be obtained with real bitumen. The gravity-employing marker press system is simple, reliable and easy to maintain. The system has performed satisfactory well in securing markers on the road surface. It is believed that the system is capable to be operated at much higher speed than was tested, however, the weight of the roller press could be reduced without effecting the performance. future firming tests may lead to a shorter roller press and consequently a reduced overall length of the marker machine.

SECTION IV

ADHESIVE DISPENSING SYSTEM

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Summary

This is the final report on the adhesive applicator system to automate the adhesive application process on the raised pavement marker machine. The objectives used in the design of this device was to increase operator safety by automatically applying adhesive and maximize the efficiency, speed, and operation of adhesive application process. The automated marker machine is designed to operate at continuous speeds of up to 10 miles per hour with markers placed at four foot intervals. The adhesive dispenser was designed for continuous flowing adhesive material without valves, orifices, or gates within the unit to impede the flow. In this report we will discuss the design, features and fabrication of the adhesive dispenser system. This report contains all the information necessary to construct an adhesive dispenser which can be mounted on an automatic raised pavement marker machine. The adhesive dispenser is compact, lightweight, and can be easily assembled. The results of the tests show that the adhesive dispensing system is capable of applying the required amount of the pseudo-bitumen at 4 foot interval from a machine travelling at up to 5 mph.

INTRODUCTION

This project involved designing an adhesive applicator to fit onto the automated marker applicator being built by Caltrans and UC Davis. The marker applicator machine has two operating modes, one to lay a continuous line of markers in patterns as in new construction or resurfaced pavement, the second mode is to place a single marker as used in the replacement of missing markers on a previously marked pavement section by cycling the machine on/off between needed markers. The adhesive dispenser will place the required amount of adhesive (3 to 4 oz) from a truck traveling at ten miles per hour, allowing the operator to remain within the protective confines of the vehicle.

The design criteria include designing a system to apply the desired amount of adhesive material at four foot intervals and synchronizing the adhesive dispensing with the highway at speeds up to ten miles per hour, which requires an application every 250 milliseconds with an adhesive flow rate of 8 gallons per minute. Another requirement was making the dispenser compact enough to fit on the marker applicator (the approximate space available measured 48 inches long by 15 inches wide).

We also needed to keep the design of the adhesive melter unit that would supply the 400 F adhesive in mind. The melter unit that U.C. Davis purchased used a hot oil circulating system to heat the adhesive material. The adhesive pumping system was designed to deliver adhesive at a rate of 30 GPM. During initial testing of various adhesive dispensing methods it was determined that to produce a discrete adhesive puddle with little or no splashing, the velocity of the adhesive stream directed toward the road surface needs to be low. To achieve this we wanted our design to use gravity flow to the road surface with large diameter pipes, channels and ports that would not restrict the adhesive flow.

DESIGN FEATURES

System Description

The adhesive delivery is accomplished through an 8 foot stainless steel belt and a 35"x4"x4" aluminum manifold assembly. The belt was designed with two bitumen dispensing ports spaced 4 feet apart. The belt wraps around the adhesive manifold (see figure 4.1) and forms the bottom of the manifold. This allows the dispenser to apply adhesive repeatedly, without any recycling time. The belt is sandwiched between Teflon seals and a bottom plate that applies upward pressure on the belt to seal the manifold. The stainless steel belt is driven (and synchronized) by a toothed sprocket with perforations along the edge of the belt (see Figure 4.2). The manifold is fed with adhesive by a positive displacement gear pump that is driven by the belt shaft. The belt drive is equipped with a clutch-brake to allow cycling on/off between successive markers. The design of the adhesive applicator uses off the shelf components wherever possible, and is easily assembled.

Components Selection

Adhesive Belt

The adhesive dispenser can operate in the new construction mode (continuous) as well as individual marker replacement mode by cycling the clutch/brake. A belt type system was chosen because it allowed a rapid repeat time for successive marker placements, and it created a compact device that fit nicely onto the automated marker machine. Stainless steel was chosen for a number of reasons for the belt. Stainless steel has a very high yield strength, it is weldable and is able to withstand elevated temperatures. The stainless steel material we chose was 17-7 PH stainless steel. This material has a yield strength of 220 KSI and a Rockwell hardness of Rc 40-44. The modulus of elasticity is 29,000 KSI with a Poisson's Ratio of .305. 17-7 PH stainless is heat treatable for excellent fatigue strength and maintains high strength in temperatures up to 800° F. 17-7 PH is considered to have higher fatigue strength than 300 series stainless but is more expensive.

Two holes for the dispensing ports are cut at exactly 48 inches from center to center. The dimension of the holes is 1.5"x2.5" oval which was determined in the preliminary tests (see section VIII). The drive holes are punched on one side of the belt with a 2 inch pitch, 1/2 inch from the outer edge, along the entire length of the belt. The belt was then electron beam welded. The complete stainless steel belt was fabricated by Belt Technology in Agawam Massachusetts. The sprockets that drive the belt were fabricated from aluminum. The diameter of the sprocket was critical in estimating the fatigue stress of the belt and calculating the pitch length. The larger the diameter, the less stress there is in the belt. This had to be weighed against the overall size of the dispensing unit and the length of the adhesive manifold positioned between the sprockets. The teeth used for driving the belt were brass flare nut fittings. These were chosen for their low cost, ease of manufacturing the sprocket, and they remained easy to replace on the final machine. The cone shaped nuts threaded onto studs which were threaded into the sprockets. Originally we chose a flat belt sprocket that was prefabricated with teeth that could adapt to the belt but we found that the sprocket casting was extremely crude for our stainless steel belt.

Adhesive Manifold and Seals

The adhesive is dispensed through a manifold. The manifold is fabricated from 2.5"x2.5"x1/8" and 4"x4"x1/8" 6061-T4 aluminum C channels and a 1/4" aluminum plate. Aluminum was chosen because of its light weight and ease of machining. The outer chamber of the manifold is a hot oil jacket that surrounds the adhesive chamber. Internal baffles were welded between the inner and outer channels to facilitate oil circulation. To protect the stainless steel belt from abrasion, Teflon seals were used between the belt and the manifold. These seals are fabricated from 1/4" Teflon sheet. The top seal was riveted onto the lower manifold surface and the bottom seal is riveted to the bottom plate. The bottom plate is attached to the adhesive frame by spring loaded bolts. The function of this plate is to apply upward pressure to the belt and thus form a tight seal on the manifold.

Other Features

The shafts are fabricated from .75 inch rod stock. The driving shaft was supported by a pair of fixed flange bearings while a pair of take-up frames are used for the driven shaft to tense and adjust the belt.

PROBLEMS ENCOUNTERED

One of the primary problems encountered during the construction of the adhesive dispenser was warping of the adhesive manifold after welded. The problem produced an uneven non-planer bottom surface for the belt to seal on. This problem was solved by placing the finished manifold in a hydraulic press and attaching a long bar to the free end. We were able to bend the manifold back straight to within 1/16 inch. The warping was not completely solved caused some adhesive leakage during testing. A better method of solving this problem would be using a good welding fixture and machining the bottom surface of the manifold flat as a final operation.

Another problem that we encountered was the engagement/disengagement of the belt with the drive teeth. Initially we made a computer model of the tooth profile and belt hole to check clearances. From this we determined that the chosen teeth would function properly. The belt was manufactured with smaller holes than we had designed because Belt Technology's recommendations. This caused the teeth to hit the belt at the tips. This problem was solved by machining the ends of the teeth into a rounded involute shape.

Another problem encountered was tooth wear. Because our drive teeth were made from brass which is much softer than the stainless steel belt, the teeth tended to wear prematurely. We had a small amount of pseudo-bitumen (shampoo and sand) leakage from the bottom of the dispenser. The amount was not enough to cause a mess or damage the device but the use of actual adhesive may increase the possibility of gumming the device and creating problems from the effects of adhesive cooling on the machine.

TEST RESULTS AND DISCUSSION

The test results show that the proof-of-concept dispensing system is capable of dispensing discrete puddles of adhesive at four foot intervals while applying the required amount of material. The adhesive system was able to dispense the pseudo-bituminous material at exact intervals of four feet. The quantity of material dispensed was adjustable by changing the feed pump rate. The positive displacement gear pump also functioned as a shut off valve when the dispensing unit was stopped.

The stainless steel belt performed well. The belt showed no signs of failure or fatigue during the tests. The holes and the seams are undamaged but the pseudo-bitumen did stain the belt. Leakage was obvious, the ability of the seal to cleanly scrape the adhesive was questionable. However, we were pleasantly surprised to find that leakage was not a major problem though it had been anticipated that there would be a significant amount of leakage from the device.

The driving sprocket had some engagement/disengagement problems and the teeth had a tendency to wear prematurely. We also had difficulty in adjusting the adhesive dispensing belt tracking.

CONCLUSIONS AND RECOMMENDATIONS

One conclusion that can be drawn as the result of this project is that it is in fact possible to produce an adhesive dispenser that can accurately dispense 400° F degree bituminous adhesive at 4 foot intervals from a continuously moving vehicle traveling at 10 mph. We can conclude from the results of our machine that to produce a reliable adhesive dispenser the construction must be held to tight tolerances to minimize operation difficulties.

The sprocket support axles and axle tracking mechanism (bearings, and axles) should have coarse as well as fine adjustments both fore and aft to allow precise adjustment for belt tracking. Another modification that would improve the performance of the adhesive dispenser is an alternate design for the belt drive sprockets. By using a ball bearing tooth design, sprocket tooth engagement/disengagement as well as the tooth life will be greatly improved. The last design modification recommended is a modification of the adhesive dispenser heating system. The adhesive melter unit UC Davis chose was not capable of providing the proper heating capacity required for hot bitumen adhesive flow and re-melting once the unit is shut down. A better design would utilize a completely detached secondary heating unit that would supply additional heat to the dispensing unit.

SECTION V

DRIVE AND SYNCHRONIZING SYSTEM

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Summary

This section of the report presents the design features of the drive system of the automated pavement marker machine and its performance during the field tests. Suggestions for the future development are as well included. The system designed is solely mechanical and all parts used are stock available components. The concept of using mechanical drive system to accomplish synchronization with minimum electronic aide was proven in the field tests.

INTRODUCTION

Using a mechanical system to drive and synchronize all belt systems is one of the principles in design of the automated pavement marker machine. The drive system was therefore designed solely mechanical, and synchronization was accomplished as much mechanically as possible . Since torque load is not significant on the whole pavement machine, the drive system functions more as a speed synchronizer rather than a torque converter. In order to be synchronized with each other as well as with the road surface, each belt has to be provided correct and non-slip speed. The delivery belt and adhesive dispensing belt had to be started and stopped at a rapid cycling rate as desired during marker placement operation. The system should be reliable, adjustable and interchangeable.

DESIGN FEATURES

System Description

The middle wheels of the automated marker machine, which took most of the machine weight, were chosen as the power source. It was considered to be the simplest and the most direct solution for the road-synchronization without any power supply involved. Two separated drive lines were arranged, one for the delivery belt and the other for press belt and adhesive dispensing belt.

A PIV transmission was equipped in the first drive line so the delivery belt speed could be varied individually without affecting the other two belt systems. Since the marker motion was not completely controlled after leaving the delivery belt, this fine tuning was very important in achieving correct marker spacing and as the result, synchronization.

Two identical electrical clutch/brakes were added in the drive lines, one for the delivery belt and the other for the adhesive belt to implement intermittent motion. The press belt was left running continuously without stop during operation. Roller chain drive was chosen for long distance drive and non-slip purpose. A pair of gears were used between the clutch/brake and the driving pulley of the delivery belt for direction reversing.

Since the driving gear was on the output shaft of the clutch which was mounted on the rear frame while the driven gear was on the shaft of the diving pulley which was attached on the front frame, the center distance of the two gears would change when the main frames were adjusted about the joint. Two links housed with ball bearings were added between two gear shafts to form a four bar linkage to keep the gears properly meshed.

The drive synchronization system is shown in Fig. 5.1. A detailed drive path with drive ratios and tooth numbers is also illustrated in Fig. 5.2 (a & b).

Components Selection

A Link-Belt P.I.V. (positive infinitely variable) drive, model H052.9w with slow speed lubrication from PTC was selected for its non-slip performance. The speed adjustment could be easily done by turning the knob during operation. Two electric clutch/ brakes, type 10 size 9 made by Kabco (refer to Appendix D) could start and stop with zero backlash. With a Voltage boosting power supply, the start-stop cycling rate can reach to 205 milliseconds which is less than marker placing rate (272 ms) in a continuous mode at 10 mph.

The roller chain and sprockets used were all No.35 (3/8" pitch). Two 76 tooth split sprockets with mated Vari-hubs were used as primary sprockets for easy assembly on the live axle. The rest sprockets were all flat sprockets with identical hubs. This feature provides the interchangeability to reduce the cost when the necessary size change needs to be made during the prototype test. Two screw-adjust chain drive tensioners and one spring loaded take-up were added to the chain drives. The shafts were all made of 3/4" cold rolled stock rod. The shafts for two timing belts were supported by self-alignment ball bearing pillow blocks. In the adhesive dispenser a pair of take-up frames were mounted where a long distance adjustment was required. The driving shaft of the adhesive dispenser was supported by flange blocks where no adjustment was needed.

A pair of nylon gears size 8 DP/42 tooth was added to the marker delivery drive to reverse the direction. Nylon was chosen to reduce the heat dissipation of the electric clutch/brake.

TEST RESULTS AND DISCUSSION

The drive synchronization system worked smoothly during tests. Correct speeds were achieved. With the voltage boosting power supply, the clutch/brakes displayed excellent start-stop cycling feature. The response capacity of two clutches was repeatable and compatible so two belts could start/stop simultaneously when two switches were manually pushed at same time. During adhesive-marker test, the cleats position was preset by try-and-error, while the electric clutch/brake for adhesive belt was engaged to the brake, to aim the marker onto adhesive puddle. The fine tuning was made through the P.I.V. transmission. The final results of the field tests proved that the P.I.V. transmission and the electric clutch/brakes had functioned effectively.

Two separate drive lines with their own clutch/brakes permitted each system be adjusted individually. However, slippage of both clutch/brakes occurred due to over torque load caused by marker jamming or improper assembly of adhesive dispenser. The slippage of each clutch/brake caused phase shift of two belts which, as a result, increased the marker deviation from the adhesive puddle. During the last phase of the project, the machine was equipped with the electronic control system and the phase shift of two belts were corrected by the electronic control system.

The driven gear was found torn at its key way, which was caused by jamming and improper assembly. A plastic gear with a steel hub could be a good solution to the problem while the heat dissipation requirement of the clutch/brake for the marker delivery belt could remain met. Slippage of the driving wheels of the marker machine was not noticeable and had little effect on the machine performance at the vehicle speed up to 5 mph.

CONCLUSIONS AND RECOMMENDATIONS

The system designed is reliable, adjustable and easy to maintain. All parts used in the system are stock ready components with minimum machining for the key ways. Synchronization was virtually accomplished via the mechanical drive system during the field tests when applying markers continuously at 4-foot interval. Traction appeared no problem with the machine weighing proximately 700 lbs at operation speed up to 5 mph on asphalt road surface.

Easiness of assembly and adjustment could be further improved. Enclosures of all the moving parts need to be added for operation safety.

SECTION VI

ELECTRONIC CONTROL SYSTEM

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INTRODUCTION

The purpose of the electronic controls is to properly sequence various mechanical operations of the automated vehicle. This is achieved by the switching of four individual mechanisms. These are the two electro-mechanical clutch-brake units and the two wrap spring clutch units. A remotely placed electronic micro-controller receives data from three optical encoders and the output of the circuit controls the various mechanisms.

The design of the automated marker machine is such that the four mechanisms- the glue belt, the delivery belt and the starwheel mechanisms must be operated intermittently. These four operations have to initiate in the proper sequence in relation to each other. The starwheels have to dispense one marker onto the marker delivery belt, the glue belt must begin moving to dispense the adhesive, then the delivery belt must begin to move in order to carry the marker to the pavement where the adhesive patch has been applied.

An electronic sequence control was required for several reasons. The marker delivery belt and the adhesive dispensing belt need to start and stop independently to each other, with the glue belt always needing to be engaged first. Therefore, the two belts cannot be mechanically linked for the synchronization purpose. In addition, any possible slippage of each clutch/brake will cause phase shift between two belts. In order to synchronize the belt engagement so the marker falls on the applied patch of adhesive, the position of the delivery belt must be checked and corrected in relation to the position of the glue belt every time a marker is being applied. Further more, the solenoid that lifts the pawl off the six toothed ratchet mechanism must be engaged for a specific time (50-150 msec). This requires a one shot type pulse to the solenoid of the wrap spring clutch/brake . If the pulse is too long, more than one marker will be dispensed because more than one tooth of the ratchet will have rotated past the lifted pawl.

The original plan was to use discrete logic circuitry for the sequencing purpose. However, the operations required of the electronic controls are far too complex to make this a feasible option. A micro-controller based control system was then developed and added to the existing discrete logic. The functions performed by the micro-controller allowed major bypassing for the original logic.

DESIGN FEATURES

Summary of Electronic Circuit Operation

The circuit provides switching of the two 12VDC loads (the clutch-brakes) and the two 24VDC loads (the wrap spring clutches). The feedback input to the circuit is provided by three optical encoders mounted on the automated marker machine. The open collector logic level signals from the encoders travel via data cable to the controller, which is located on the towing vehicle. The micro-controller uses these inputs to determine the synchronization of the various clutch operations.

To activate the starwheel mechanisms, an open collector logic level signal is sent by the logic circuit to an electronic relay unit, which uses MOSFET semiconductors to switch the 24VDC, 325mA solenoid load for the wrap spring clutch units (only one will be triggered at any one time). A positive logic pulse of approximately 30-150 msec is required from the logic circuit in order to dispense one marker through the starwheels. When the 24VDC circuit is activated, the wrap spring clutch solenoid lifts its pawl for the said amount of time. One tooth of the six-toothed ratchet rotates past, allowing the starwheels to rotate one sixth of a turn thereby dispensing one marker.

To control the clutch-brake units, an open collector logic level signal is sent to the over voltage power unit. This unit provides switching of the 12VDC clutch-brake loads. In addition, it produces a momentary over-voltage pulse (~50msec, 6X over-voltage) to the unit in order to engage the clutch or brake more quickly.

The controller is designed to dispense markers in two different modes, single or pattern. In single marker mode, the type of marker (reflective or non-reflective) is selected and the start button is pressed to apply one marker.

The machine will apply this marker, reposition and stop the glue and delivery belts and then wait for the next operation.

In the pattern mode, the start button initiates a continuous cycle of marker application. The pattern tested was Caltrans Standard Detail 14, in which four non-reflective markers are applied at a four foot spacing, one reflecting marker is applied 18 feet from the last non-reflecting marker, 18 feet are again allowed to pass and the cycle repeats with the application of four non-reflecting marker.

Circuit Principle

The discrete logic portion of the circuit is five magnitude comparators. Each comparator has two 8-bit binary inputs, A and B. There are three outputs: A<B, A=B, A>B. Two hexadecimal marked rotary dip switches provide an 8-bit binary word at one input of the comparator and the other input comes from the absolute encoder whose position is being measured.

The shaft of each absolute encoder is geared with the drive pulley of its respective belt. The gearing is such that one half of one full revolution of each belt equals one full revolution of its respective absolute encoder. Each turn of the absolute encoder shaft will cycle the encoder through 128 counts. The 7-bit word of the encoder goes to the magnitude comparator. In effect, various linear belt positions can be sensed for the glue belt and the delivery belt and the belt positions can be set and adjusted for by setting the rotary dip switch inputs of the various comparators. The comparators process the 7-bit binary input data from the absolute encoders to A<B, A=B, A>B outputs. From there, the micro-controller processes these inputs and determines the outputs.

The incremental encoder is used for distance measurement. It is geared such that one revolution of the 17.5 inch circumference press belt pulley equals one revolution of the incremental encoder shaft. Hence, every 17.5 inches the vehicle travels, 128 square wave pulses are sent from the incremental encoder to the circuit. The circuit uses this data to determine the marker spacing in the highway pattern. The resolution of the incremental encoder was chosen as 128 counts per revolution because the logic circuit uses a 12 bit latch and 12 bit counter to space the 18 ft distance in the marker pattern. A higher resolution encoder would have required a latch and counter with more bits.

Basic Construction of Electronic Controls System

Main Circuit

In addition to the micro-controller, discrete logic is used. The discrete logic portion of the circuit is based on the 74HC CMOS digital logic family. The circuit board is wire wrapped and mounted in a metal chassis box. There are despiking capacitors at each i.c. input voltage and the metal chassis box is grounded with the foil shielding of the data cables. The supply voltage comes from a 5VDC, 3A power supply which converts from 120VAC. The combined current consumption of the main circuit and the optical encoders is approximately 900 mA (the encoders are powered from the same power supply). The contact toggle and pushbutton switches are all debounced.

Rotary adjust dip switches are used to input adjustable 7-bit words to the circuit's digital logic magnitude comparators. The marking on the dip switches are hexadecimal and the actual word that is input to the comparator is natural binary. There are four hexadecimal l.e.d. displays to show the position of each absolute encoder. There are two hex digits for each of the two absolute encoder. The 7-bit binary number is fed into the display and is converted to hexadecimal and displayed. This way, only two displays are required to display the reading of each encoder. Adjustments in the hexadecimal marked dip switches are made easier since the encoder readings are also in hexadecimal.

Optical Encoders

The absolute optical encoders are sealed metal casing units manufactured by B.E.I. They feature a 7-bit natural binary output with an open collector driver. The units operate on 5VDC, ~250mA. The internal code disc in the encoder upcounts in Gray binary code to prevent false readings. The Gray code is then converted to natural binary output. The resolution is 128 counts per shaft revolution.

Overvoltage Power Unit

Application of an over voltage pulse to the clutch or brake of the clutch-brake unit will engage the given mechanism more quickly than applying the nominal 12VDC (~3A) to the load. The over-voltage power unit applies an over-voltage pulse (~6X nom.) for ~50msec and then drops the voltage down to the nominal. The unit operates on the principle of pulse width modulation. A logic level 'high' from the main circuit causes an over-voltage pulse to go to the clutch of the given unit and a 'low' causes an over-voltage pulse to go to the brake of the given unit. A data cable from the main circuit carries the open collector signal to the over-voltage unit and there are four power lines going to each clutch-brake unit from the over-voltage unit, one line for the clutch, one for the brake, and two ground wires.

Relay Unit

The wrap spring clutch solenoids are each 24 VDC, 325mA loads. The main circuit switches these loads by using MOSFET semiconductors. The logic level signals and the 24 VDC circuit are optically isolated. The relay module is powered by a 9 volt battery cell.

Description of Micro-440 Controller

The micro-controller used is the Blue Earth Micro-440. It is an 83C51FX based micro-controller that retains its CMOS memory and internal clock with a battery backup which is designed to last up to 10 years. It contains 12 digital I/O lines and 7 analog input lines. For this application, 11 digital and 5 analog lines are implemented. The programming is done in BASIC code, which utilizes the Micro-440's own 8K floating point internal BASIC interpreter. The user may save up to 8K worth of programs in the controller's memory. When used as a stand alone in the field, the Micro-440 automatically runs the first program in memory on startup. Programming of the controller is done through its RS-232 communication lines. A microcomputer using RS-232 communication and a serial communications program such as Kermit© or ProComm© are needed in order to communicate with the controller. When programming the controller, it is connected to the computer terminal's serial port. Further details concerning the Micro-440 and its programming can be found in the Micro-440 User's Manual.

BASIC Program Description

The BASIC program used to control the sequence of operations of the automated vehicle is divided into two parts. One section of the program handles single marker application. In this mode, all operations reset and wait after application of a discrete marker. The other section handles the continuous pattern application in which the operations continue automatically, as the pattern necessitates. A program which applies single marker and the pattern of Caltrans Standard Detail 14 is included in Appendix E. Various patterns can be applied by changing the subroutine of the program.

TEST RESULTS AND CONCLUSIONS

The electronic control system was tested on the RPMM machine both in lab and on roadway. The RPMM controlled by the electronic system was able to place a single marker at the spot desired, as well as lay a pattern when both marker and adhesive were applied. Neither of the above was possible to be achieved by manual operation. The alignment of the marker and adhesive puddle was accomplished through adjustment during the operation without stalling the machine.

However, it was found that the electronic controller was sensitive to the vehicle speed. The controller performed well only at a particular speed level (approximately 2.5 mph). The sequence was confused at either higher or lower speed. It also was found that the micro controller occasionally malfunctioned due to electrical noise from its power supply and the field environment in general. It was necessary to reset the controller when this occurred. A better noise filter is suggested for the future application.

The performance of the RPMM machine demonstrated that a programmable microcontroller-based sequence control system is feasible and cost effective solution for an automated raised pavement marker machine.

SECTION VII

MAIN FRAME

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INTRODUCTION

This is the final report on the Main frame assembly used to support the entire apparatus. In this report we will discuss the design features and fabrication of the main frame assembly. This report contains information necessary to construct the frame assembly as well as results and conclusions from testing and operating this unit. Also included in this report are recommendations for future modifications that would increase the usefulness and reduce the cost of the frame assembly.

DESIGN CRITERIA

The objectives used in the design of this frame were as follows: 1) provide strong support to all the various components that the marker machine would contain, and 2) allow space for additional marker storage capacity for future modifications. The automated raised pavement marker machine has three main sub-assemblies; The dot dispensing system, the marker securing, and the adhesive dispensing system. All three systems were designed to operate within close proximity to the ground. The main frame is responsible for supporting these sub-assemblies as well as all their related components. There were a number of factors that lead to the final design of our frame assembly. Caltrans maintenance personnel wanted a device that would mount on the side of a truck that could be lowered into position for actual operation. This requirement initially forced our frame design to be as narrow as possible. The facilities and equipment that were available to our project team were limited to a single vehicle for two separate projects and the limited shop and storage facilities at U.C. Davis. This lead us to the conclusion that we would not have the luxury of mounting this machine on the side of a truck without major conflicts with the other projects and work space problems. For this reason we chose to make the unit a separately towed device or trailer. This would allow us the freedom to work independently of other projects. Furthermore, as long as the design remained narrow, we could retrofit the machine to the side of a vehicle for future maintenance operations. Because this was to be a proof-of-concept device, the operating method would not be as much a concern as in an actual "road ready" piece of equipment.

DESIGN FEATURES

The overall dimension of the frame is 174"x36"x28". The main structure of the frame was designed using 2″x3″x1/8″ mild steel tubing. This material was chosen because it can be easily welded, provides flat surfaces for mounting or welding additional components, and is strong enough to withstand stresses that might be placed on the machine while being used on the highway. Sub-structures of the main assembly were designed with 1″x3″x1/8″ mild steel tubing.

The frame had to support the three main subassemblies, which required mounting in series (along the same line) with each other. This required the frame and the complete machine to be approximately 12 feet long. The machine was designed to a six-wheeled trailer for several reasons. First, the various systems also required support at close proximity to the road surface, the frame required support wheels along its 12-foot length. This required the frame to have additional support wheels midway. Secondly, one pair of the wheels has to be the driving wheels to power three sub-systems. The midway location allows the driving wheels take most of the machine weight therefore sufficient traction could be obtained to prevent the tire slipping. Furthermore, the "tail wheel" were considered necessary in order to assure the press belt to have uniform ground clearance, so that it can effectively firm the markers on the road surface. We felt that this might create some problems in operation. One, the unit would have a total of six wheels in contact with the ground at one tine. This would make the unit difficult to turn. Secondly, the center wheels would be possibly lose contact with the pavement when the unit traveled over uneven surfaces. To alleviate these problems the design was revised from a rigid the frame in two sections with a pivot point connecting the two together (see figure 7.2). The front section was designed to have one set of support wheels, while the rear section was designed to have two sets of wheels to support the unit and maintain close proximity to the road surface. This arrangement would allow the machine to travel over uneven road surfaces without the center wheel losing contact with the pavement. This configuration would also make the unit easier to turn. The front set of wheels are pneumatic 14″ diameter ball bearing swivel casters which allow the machine to follow the towing vehicle without tire skid. The other four wheels are 16″ diameter pneumatic wheels similar to that used on small trailers. As shown in figure 7.2, the frame also has supports and flanges for the various bearings and pulleys that are part of the individual systems. The towing hook with a standard 2" ball hitch was designed such that it pivots during transportation.

PROBLEMS ENCOUNTERED

There were two problems that occurred with the frame we designed. After the machine was assembled the center of gravity turned out to be ahead of the center wheel on the rear frame section. This caused the unit to rotate about the pivot point between the two sections, pick up the rear tires, and rest on the components at the center of the unit. To remedy this problem we added two rigid links between the two frame sections to eliminate the pivot. The link was a 1/2" turn buckle which provided adjustment in the frame assembly. The second problem encountered with the frame assembly became evident when we towed the frame assembly to the equipment shop for painting. The front casters had a violent shimmy at speeds over 3 MPH. We remedied this problem by designing a second hitch for "high speed" towing to and from the test site. This hitch was designed to pick up the complete front end of the unit, thus allowing the machine to be towed at higher speeds. We found during testing that when the unit was fully assembled the shimmy problem was eliminated.

CONCLUSIONS AND RECOMMENDATIONS

The results from our frame design and construction illustrates that the frame design is paramount in the overall design of the unit. It not only provides the support for the rest of the machines systems but it is the most visible portion of the device. Proper functioning of the machines sub-systems as well as ease of transportation and operation relies heavily on the well thought out frame assembly. We can conclude from this project that the frame should remain as simple and compact as possible. Also, the weight and balance of the finished machine must be taken into consideration when first designing the frame, not only to make certain that the frame can support the entire load, but to ensure that the unit will operate as it was intended. The next generation unit should consider a frame that will in fact mount on to side of a truck. Refinements in the various systems will result in reduced overall length of the machine and thus allow the device to more easily fit along side a maintenance vehicle.

SECTION VIII

SYSTEM TESTING

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INTRODUCTION

Prior to the construction of the adhesive dispensing unit, the preliminary tests were performed to verify its design concept and determine several important design parameters as well as to discover a suitable substitute of bituminous adhesive for the machine testing purpose. A report of the normal force test, which was conducted at concept developing stage, is also included in this section.

The system testing was conducted in three phases. Phase I, stationary testing, focused on the final construction, implementation, and testing of the RPMM components, sub-systems and integrated system in a laboratory environment. Phase II, field testing, focused on the assessment of the RPMM's on-road performance. During this phase of the field testing, the RPMM machine was manually operated. The final phase, Phase III, tested the implementation of the Electronic Control System (ECS) onto the RPMM through both stationary and field testing.

PRELIMINARY TESTING

ADHESIVE TESTS

The objective of the adhesive tests was to discover a satisfactory substitute for the bituminous adhesive. Since the adhesive melter purchased (Berry BMA-200 Melter) failed to sufficiently heat the dispensing area of the RPMM machine and the 20-foot long hose, a long down-time was required during machine start-stop in field tests. A cold-applied substitute would certainly smooth the prototype testing process and thus speed up the research.

Criteria

Since an adhesive substitute is only for machine test purpose, the viscosity was the main property which needs to be concerned. Therefore, the criteria was established such that the satisfactory substitute (pseudo-bitumen) should have the same viscosity of the bituminous adhesive at the application temperature (400°F). The chosen material or mixture should also be uniform in density, easy to clean and relatively low cost.

Test Procedures

To simplify the procedure and reduce the cost, the viscosity was expressed by the time it takes for a finite amount of the material to empty an 8 oz. funnel. First, the viscosity of the bituminous adhesive was determined. The bitumen was heated with an electric melter to approximate 400°F, and was filled into the funnel. The time to empty the funnel was then recorded with a stop watch. The measurement was repeated 5 times. The average time for the bituminous adhesive to exit the funnel was approximately 18 seconds. The same procedure was followed to measure the viscosity of various materials under investigation.

Results and Discussion

A number of different ideas were tested. Water, the first test material idea, was inexpensive and harmless but its viscosity did not resemble that of the bituminous adhesive. A combination of soil and water were then tested but the results were similar to water. The 80W-90 and 80W-130 machine oils were also considered but they were messy as well as costly and failed to reproduce the required viscosity. Finally, ordinary shampoo was tested and the expected viscosity was achieved. It is inexpensive and easy to use as well as to clean-up. Its viscosity, however, is quite temperature dependent. In order to obtain the desired value of viscosity, very fine sand was added at high temperature and water was added at low temperature. This addition was found very effective in adjusting the viscosity of shampoo and the required value can always be reached. (See Table 8.1 in the Appendix.)

Conclusions

Shampoo and its mixtures with water or sand were chosen as the pseudo-bitumen for the prototype testing purpose. Throughout the testing, the shampoo, shampoo/water, and shampoo/sand substitutes worked well without any problems. Shampoo bought in half-gallon sizes were cheaper than the standard 16 oz. size. Approximately 10 gallons of shampoo were used during a two month testing period. Some of the shampoo was used repeatedly. The pseudo-bitumen proved to be compatible with the adhesive dispenser, and was used consistently throughout all of the testing phases.

Adhesive Dispensing Tests

This testing was conducted prior to the construction of the adhesive dispensing system. The purposes were first to test the design concept of the adhesive dispensing mechanism, and then to determine the possible usage of the stainless steel belt and Teflon seal, and correct hole size of the belt.

Test Set-up and Equipment

A wooden track-based testing device simulating the adhesive dispenser designed was constructed (See Figures 8.1 in the Appendix). On the actual vehicle, a stationary adhesive container (manifold) was surrounded by the rotating stainless steel belt. For testing purposes, the wooden track with a stainless steel belt on its top surface was stationary while the adhesive container was pulled along track via a cable and a set of pulleyes driven by a half-horsepower, 1750 maximum rpm, electric motor. This setting allowed the simulation of the zero relative velocity between the belt and the ground. The speed of the container was monitored using an oscilloscope and adjusted through the speed controller of the motor. Two toggle switches positioned 2 feet apart, both triggered by the moving container, allowed the oscilloscope to display the necessary information to calculate the container velocity. The average speed of the container was 9.2 mph.

The pseudo-bitumen with required viscosity was filled in to the container and its level in the container was measured. The volume of the pseudo-bitumen dropped out from the belt holes was measured with a measuring cup.

Results and Discussion

The overall performance of the the dispensing device was examined. The pseudo-bitumen, dropped out from the moving container at approximately 9 mph through its 34x1.5" slot and the belt hole, formed a nice circular puddle on the catching plate.

Eight different sizes and shapes of the belt holes, ranging from 1.5" diameter circle to 3.5"x1.5" slot, were tested. The results are shown in Table 8.2 in Appendix A. The amount of pseudo-bitumen dispensed from a 2.5"x1.5" slot was 3 oz. which was found to be adequate to effectively adhere the marker onto the ground.

Two 1/8" plastic seals with different slot configuration were tested. One has a 34"x1.5" round ended slot while the slot on the second seal is slightly narrowed down from the center to the ends. The length of the slot was found adequate to allow the desired amount of the adhesive to dropped out at the operation speed of 9 mph. Adhesive seepage was observed during the tests and no significant different in seepage was found between two seal slot designs. Since the 0.010-inch thick steel belt was supported by the wooden block, a reasonable perfect contact between the belt and the seal was not possible to be acheived. Furthermore, the total weight of the wooden container filled with pseudo-bitumen was not sufficient to produce a tight belt-seal contact. Seepage was greatly reduced by increasing the additional weight on the container. Therefore, the experimentation showed that the seal design was not much a factor, only the normal force applied to the seal helped elimination of seepage. Thus, the simplest seal design was chosen for the adhesive dispensing unit on the RPMM machine.

Due to time limit, no complete tests was conducted to investigate the effect of the adhesive level in the container on the amount of Pseudo-bitumen dispensed, therefore no conclusion was drawn.

Conclusions and Recommendations

The results of the tests demonstrated the possibility of applying a mechanism with a slot-bottomed container and a moving belt with holes to dispense the adhesive from a moving vehicle. The usage of a thin stainless steel belt and Teflon seals was confirmed. The dimension of the belt holes was determined to be 2.5"x1.5" for the final fabrication.

In order to eliminate the adhesive seepage, attention has to be paid to fabrication of the bottom plate and the manifold of the adhesive dispensing unit. The surfaces have to be carefully leveled and any deformation due to welding has to be corrected. Seepage can also be reduced by adjusting the springs to increase the force applied to the belt from both sides.

Normal Force Tests

Normal Force Tests-Procedures

A normal force is required when placing markers to reduce drift and increase adhesion. For best results the normal force must be sufficient to ensure good road contact, while not significantly displacing the marker from its target position. This test was designed to determine the normal force required and explore the feasibility of using a rolling wheel to impart the force. The normal force test used a lbs scale with an operator simulating the current application process. The rolling wheel apparatus was made by rigidly mounting three 16 inch wheels on a shaft. Consequently, all three wheels rotated as a unit. The two outer wheels were inflated to 45 psig while the inner (impact) wheel was tested first deflated, then inflated to 20 psig. This created a 1/8"-3/4" clearance between the road surface and the wheel. The assembly weighed 25 lbs and a 10 lb weight was used to increase this to 35 lbs. Two 18' tracks were used to glide the wheel fixture over the markers. A liquid asphalt @ 60 poise and real bitumen were used for the tests.

A video camera recorded the results. A measuring board was used to measure the marker displacement. The initial test to determine the force required was carried out with the scale placed on the ground and three different operators simulating the force that would be used to set the markers. Next, we applied bitumen @ 375° F and placed a marker on the adhesive. The markers were then removed and the thickness of the adhesive layer was measured. To determine if a rolling wheel would produce sufficient force, a marker was placed on each type of adhesive, the displacement was measured, and the flow characteristics were observed to determine a correlation between the liquid asphalt and real bitumen.

Results and Conclusions

The initial floating tests clearly showed significant differences between the liquid asphalt and the real bitumen. The viscosity and adhesion appeared quite different. Consequently, only real bitumen was used for the remaining tests. The maximum normal force that our operators could achieve simulating the application process was 30 lbs. The average comfortable force was 10 lbs. The layer of adhesive range was 3/32" to 3/16". The displacement from the rolling wheel was generally 1/4" and 5 degrees or less. It was evident from the video that the downward force reduces the marker float but does not completely eliminate it. See Table 8.3 in the Appendix. The normal force the operator applies was probably no more than 10 lbs and over continuous operation is likely to be 3 - 5 lbs. The thickness of the adhesive layer varied from 3/16" to 3/32", the inner layer being achieved between 10 and 30 lbs. It appears that the viscosity of the bitumen and the road texture limits the adhesive layer thickness to approximately 3/32". This test also shows that the rolling wheel approach for securing the markers produces a sufficient downward force to approach the thin layer of adhesive necessary for proper marker placement, and the displacement of the marker appears acceptable.

PHASE I: STATIONARY TESTING

All Phase I tests were conducted in a laboratory setting. The purpose of this section was to test the different sub-systems of the RPMM. The experimentations attempted to duplicate real operating conditions.

Test Set-up and Equipment

The RPMM was elevated approximately 8" off the ground using cinder blocks as vertical supports and 4"x4" steel tubings as horizontal supports. A 1/2 hp AC motor and an additional two stage V-belt drive chain were mounted on the machine to power the driving wheel. A ground simulator was developed to simulate the road surface during the stationary tests. It consists of a 12'x1.5' rectangular plywood plate, a 30' long wooden guiding track and four pairs of rollers. The plate was placed underneath the right driving wheel of the RPMM machine. It was driven by the driving wheel via friction and rolled on the guiding track. The vertical position of the guiding track can be adjusted to assure sufficient friction between the tire and the plate, so the synchronization of the plate and the three belt systems can be achieved. The ground simulator was long enough so that two successive markers and adhesive puddles could be placed on it. The right front wheel was taken off allowing the simulator to slide all the way through.

When the synchronization between the marker delivery belt and the adhesive dispensing belt was not tested, a treadmill was used to simulate the ground and a three foot long trough was placed under the adhesive unit to collect the dispensed materials. A power supply enclosure was built to integrate a 24 volt D.C. and a 12 volt D.C. over-voltage power units and the manual operating switches. All AC power was from wall outlet during this phase of the tests.

Due to high viscosity of the pseudo-bitumen, the gravity feeding was found not a practical way to feed the adhesive into the manifold. A positive displacement gear pump was added to the dispensing system. The pump was driven by the steel belt of the dispensing unit via a chain drive. A 5 gallon plastic bucket was mounted on the main frame and connected to inlet of the gear pump with a 1" hose. A valve was used to control the adhesive flow from the bucket to the pump.

The machine was operated manually by manipulating the toggle switches and push-buttons.

Results and Discussions

The Marker Loader System

The hopper placement was crucial. If either hopper was slightly off-center, the markers would seat on the starwheels incorrectly. This caused the starwheels to jam. Once the hoppers were adjusted and aligned properly, the problem ceased. The hoppers worked well after adjustment, with one detectable problem. Due to large clearance between the round dot and the inner wall of the hopper, the dot had a tendency to shift to one side or the other. This shifting contributed to starwheel jamming. Reducing the gap would eliminate the dot shifting problem.

The overall performance of the wrap spring clutches was greatly affected by operator' skill. the time duration that the button was pushed and the force applied on the button were critical. If the button was pushed too long, two stops of the clutch shaft would pass before the actuator was released. As result, two markers were loaded, resulting in a delivery belt jam. If the applied force was too small, the wrap spring would not be able to engage the starwheel. The starwheels worked very well. With a skillful operator, the whole loading system performed satisfactorily when the remote speed control of the electric gearmotor driving the starwhells was set at 50% of its full range.

Electric Clutch/Brake

The overall performance of the clutch/brakes was very impressive. Using the over-voltage power source, the clutch/brakes engaged and disengaged almost immediately. At slower speeds, the delivery belt and adhesive dispensing belt stopped instantaneously, while at higher speeds there appeared only to be an extremely small lag time between the signal and consequent stoppage. There were no noticeable durability or reliability problems with the clutch/brakes. For all practical purposes, they fulfilled all of the project's requirements. The clutch/brakes and over-voltage power source are two of the key components which contribute to the RPMM's excellent, overall performance.

Marker Delivery System

The interaction between the belt and its pulleys was satisfactory. The belt did not slip off or become misaligned. Furthermore, the delivery belt was very durable and displayed no signs of failure or fatigue. The cleats on the belt worked quite well. They were able to push the markers through the marker stopper without problems. The cleats were also very durable and were never torn from the belt. Although it was not tested at speeds higher than 8 mph , It was believed that it can handle higher speeds without a loss of performance.

The stopper was tested over a simulated speed range up to 8 mph. It worked well in the 2 to 4 mph range. The marker traveled on the delivery belt from the hoppers, stopped at the stopper, and released with the cleats. The marker and stopper were in contact until the cleat pushed the marker past the stopper. At speed beyond 4 mph, the cleats sometimes passed through the stopper leaving the marker behind. The next cleats had to push two markers, which caused jam. At higher speeds, however, the marker slipped under the stopper before the cleats came. This would causing the marker spacing to vary a great deal. The addition of a steel plate behind the stopper increased the resorting force and helped a little. At higher speeds, 6 to 8 mph, the problem still existed.

A 1/4" thick rubber strip was added to the bottom of the guard rail approximately 2" in front of the original stopper. This rubber strip helped the stopper to stop the marker at all speeds ranging up to 8 mph. The marker no longer slid back up the delivery belt and was in contact with the stopper the entire time until the cleats released it. The height of the stopper was approximately 1/16" from the delivery belt.

Adhesive Dispensing System

The positive displacement gear pump works very well. The dispensing unit was able to discharge the required amount of the adhesive at every half belt cycle. The stainless steel belt performed well showing no signs of failure or fatigue.

Problems with the belt/sprocket system are of an accumulation of various problems. Starting from manufacture, the manifold was warped. Consequently, the shafts for the sprocket were not parallel, causing uneven wear to the sprocket teeth. This uneven wear was impacted by the wear of the stainless steel belt against the brass teeth. Grinding of these teeth was quite evident. Another problem occurred upon following manufacturer's recommendations for reducing belt hole sizes. In testing, these new holes were found to be too small. In consequence, once again the brass teeth were introduced to undue stress, and hence grinding. In retrospect, a better tooth design would be one in which the teeth are made out of sturdier material, are of a smaller height, and have better clearance with the belt, perhaps a ball bearing type tooth, such as that suggested by the belt manufacturer.

The Teflon seal worked fairly well using the pseudo-bitumen. However, the leakage was obvious. When the manifold is full and the dispenser is not operating, however, a very noticeable amount of pseudo-bitumen seeped out at slow but constant rate. Increasing the spring tension by tightening the bottom plate bolts helps retard the seepage slightly but increases seal wear.

PHASE II: FIELD TESTING (Manual operating)

The purpose of this phase of the field tests was to discover any problems not encountered during the static testing phase and prove the RPMM was capable of performing as expected. These field tests focused on the performance of each system as well as the overall performance of the RPMM under the road operating conditions. Since the electronic control system had not been completed then, the machine was operated manually in this phase of the field tests.

Test Set-up and Equipment

The RPMM was transferred to the off-campus test site. The safe speed range while towing the RPMM to the test site was up to 15 mph depending upon the road surface. The test site was a two lane, lightly traveled road. Since the road had only two lanes, the crown of the road was very noticeable. The road surface was void of pot-holes and generally in good condition. Testing was conducted on both sides and in the center of the road. The two power supply units were powered by a 120 volt A.C. generator. Both the power supply enclosure and the generator were mounted on the towing vehicle.

Test Procedure

Both hoppers were completely filled with markers. The adhesive container was filled with water initially. Later, the adhesive feed container was filled with pseudo-bitumen. Since the tests were conducted under the condition of low ambient temperature, water was added to the shampoo to simulate the flow characteristics of the bituminous adhesive. The amount of water added to the pseudo-bitumen varied from day to day due to temperature variations. The field tests included only continuous marker placement at speeds up to 5 mph. Since the Electrical Control System was not completed, the RPMM was operated manually. Approximately 100 markers were placed on the roadway each test pass. Approximately eight test passes were done each testing day. Field tests lasted two weeks. Initial tests placed only markers on the road surface. Then adhesive dispensing tests using water were done. Later, all systems of the RPMM were tested using water with markers. Finally, pseudo-bitumen was used with markers simulating real operating conditions. In order to synchronize the marker delivery belt and the adhesive dispensing belt so the markers would fall directly onto the pseudo-bitumen puddle, the positions of the marker delivery belt cleats and the steel belt holes were preset manually by a trail-and-error method. During marker-adhesive tests, both belts were running continuously

Problems Encountered

Raising the RPMM and transporting the RPMM to the test site created problems. The ground clearance of the tow-bar mount was too small for a floor jack to fit in. Thus, two 2" thick wooden blocks were placed under the front wheels to raise the RPMM sufficiently so a floor jack could be used to elevate the RPMM. The frame joint, however, failed to remain fixed resulting in extreme frame flex. The shaft allowing engagement of the clutch/brake for the adhesive dispenser permanently deflected due to the frame flex. This did not disrupt operation. Pulling the RPMM on level asphalt during operation caused two clearance problems. First, there were clearance problems on uneven road surfaces due to the height of the adhesive dispenser, marker chute, and press belt. The markers already adhered to the ground also created similar problems. Great care was needed to insure these components not to be damaged.

Results and Discussions

The RPMM successfully placed reflective markers and non-reflective markers on top of pseudo-bitumen puddles during continuous operation. The average spacing deviation was ±1.5" at 4-foot interval, and the average rotation of the reflective marker was less than 5°. Marker drift was unnoticeable. The delivery belt jammed during operation, causing minor damage to the nylon gear. No other problems caused a stoppage of operation. The P.I.V. transmission successfully allowed the synchronization of the markers and pseudo-bitumen. Breakage of the reflective markers occurred at high speed. The leading edge corners of the markers were chipped. The breakage, however, only occurred when pseudo-bitumen was not used. Placing the markers on the road in a straight line was difficult. When the markers fell onto the pseudo-bitumen and were secured to the ground by the pressure belt, no traces of pseudo-bitumen were found on the top surface of the marker. Lastly, it was possible to use markers repeatedly during the tests because the markers could be picked up from roadway and the pseudo-bitumen could be easily removed from the marker.

Conclusions and Recommendations

The raised pavement marker machine is capable of placing both reflective and non-reflective markers continuously at vehicle speed up to 5 mph. The RPMM successfully displayed proof-of-concept.

Modification of the chute design is suggested toward better control of the marker motion, so that the rotation and breakage of the reflective marker could be eliminated. Enhance the nylon gear strength could eliminate the possibility of ruin the gear. A torque release mechanism would protect the subsystems and clutch/brakes from damage causing by over load due to marker jamming.

PHASE III: ECS TESTING

Upon the completion of the electronic control system (ECS), the RPMM machine was tested again. The purpose of this final phase of the tests was to examine the function of the microcontroller-based control system as well as the overall performance of the marker machine integrated with the ECS.

Test Set-Ups and Procedures

The final phase of the tests was conducted both in the lab and on the roadway. The testing environment and set-ups were the same as that in phase I and phase II. The long wire/cable connection allowed the electronic control unit with the power apply enclosure to be mounted on the towing vehicle during the field tests. In the stationary testing, only the treadmill was used to simulate the road surface. The remote speed control of the electric gearmotor which drives the starwheels was set at 80% of its full speed for all test runs.

In the lab testing, the responses of three subsystems (i.e. the starwheels, the marker delivery belt and the adhesive dispensing belt) was first checked during the dry runs. After necessary mechanical and electronic adjustments were made, markers and adhesive were then applied. Only single marker mode was tested. Since the 30-foot ground simulator was not used, the synchronization of the marker delivery belt and the adhesive belt was not able to be checked.

In the first stage of the field tests, the single mode was tested and the alignment of the marker and the adhesive puddle was checked and adjusted. The pattern mode was then tested in the second stage. The overall performance of the RPMM machine under both modes was evaluated in the final stage of the field tests.

Test Results and Discussions

The tests of this final phase was mainly a debug processing for both software and hardware of the electronic control system. Single marker mode was accomplished without encountering too many problems because less sequencing was involved. During pattern mode testing, changes in both program and circuitry were frequently made in order to make the system work or to improve its performance. During this process, various types of ground layouts were observed, such as double markers or even triple markers at same location, lone adhesive spots without marker or lone markers without puddle. Starwheel jams occurred occasionally probably due to long trigger pulse.

The pattern was successfully laid in the fianal stage. In a three-run demonstration along the entire testing road, only one mistake (double round dots) was made. The alignment of the marker and adhesive puddle was good and it can be adjusted during operation without stopping the machine. However, the spacing deviation between the reflective marker and the round dot fell in the range of ± 2 foot.

The electronic controller was found sensitive to the vehicle speed. The controller performed only at a particular speed range (approximately 2 mph). The sequence was confused at either higher or lower speed, or when the speed was not consistent. Inconsistent speed was considered the main contribution to the variation of the 18-foot spacing. It was also found that the micro controller occasionally malfunctioned due to noise from the gasoline generator or other source in the field environment. Reset was necessary when it occurred.

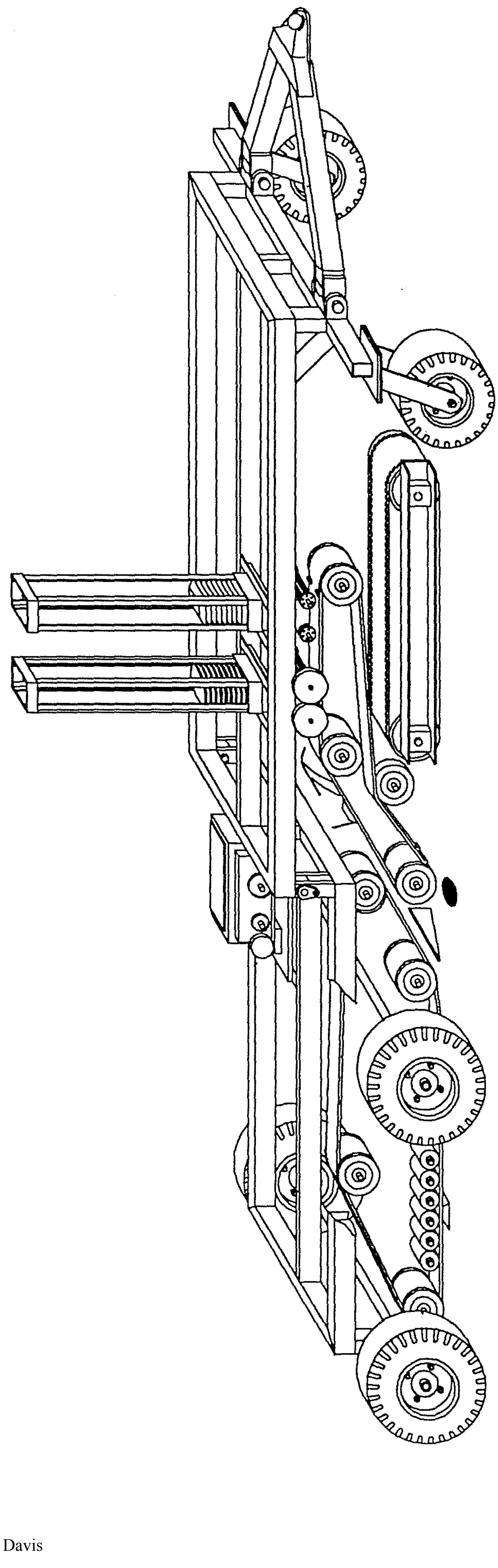
The overall mechanical performance was good. Starwheel jammed due to a couple of over sized round dots. The wrap spring clutch/brake for the reflective marker did not functioned as well as the other one. This is possibly due to its weak solenoid.

Conclusions and Recommendations

The RPMM conclusively demonstrated the ability of a mechanically linked system to affix raised pavement markers to the road surface with minimal additional aide. Successful single marker application was accomplished. With the incorporation of a micro controller to the ECS, the option of applying various continuous pre-selected pattern of markers was made possible.

The program and the hardware circuitry could be perfected in order to improve the machine performance as well as to increase the operating speed.

APPENDIX A
FIGURES
Table of Figures



AUTOMATED CONVEYOR DOT MARKER

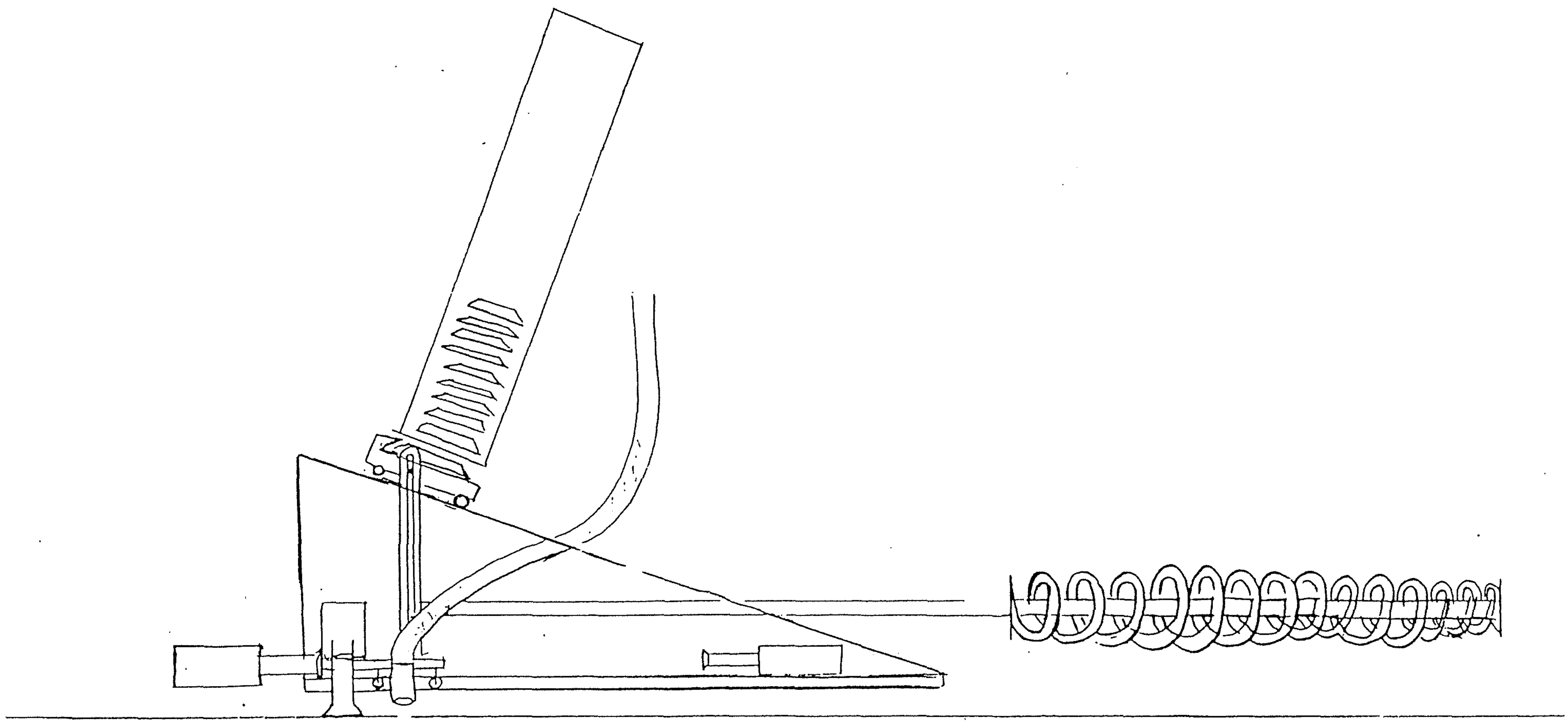


Fig. 1 Braker raker.

Sketch of the Testing Prototype of Brake-Racker

7/25/90

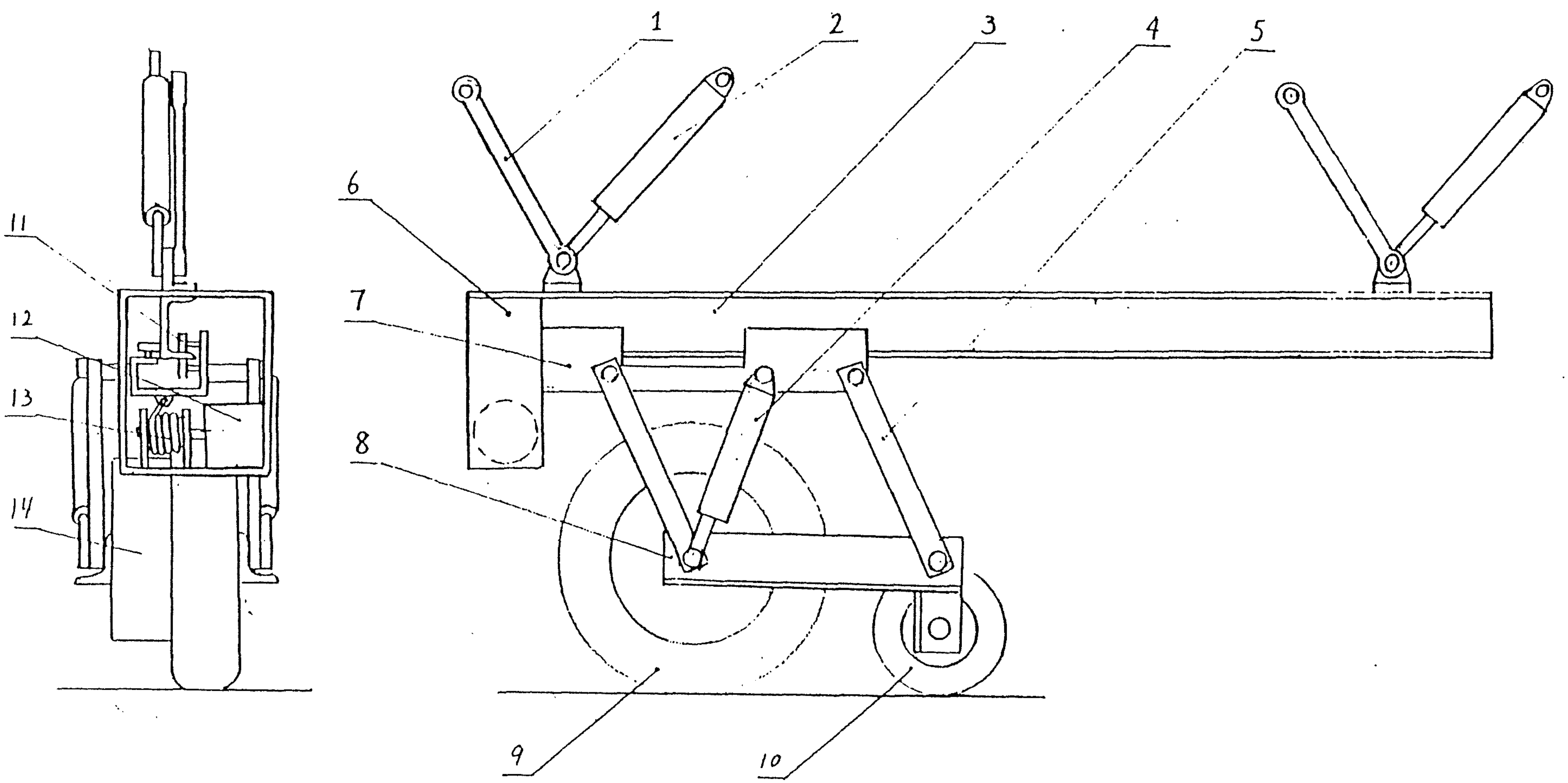


 Fig. 2 Sketch of the testing prototype of braker - raker.

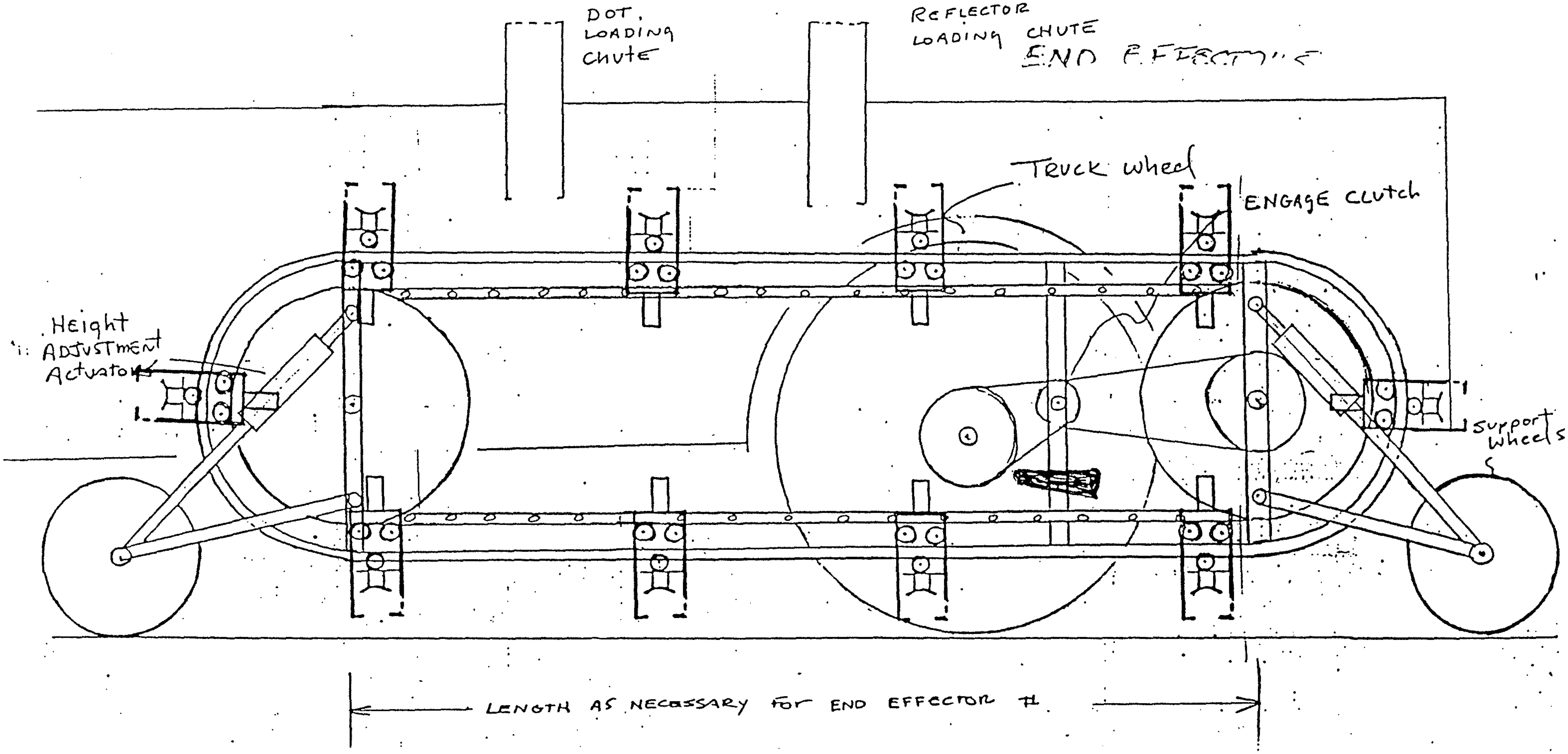


Fig. 3 Modification to phase I machine.

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Mechanical Composition of the Marker Applicator System (Phase II)

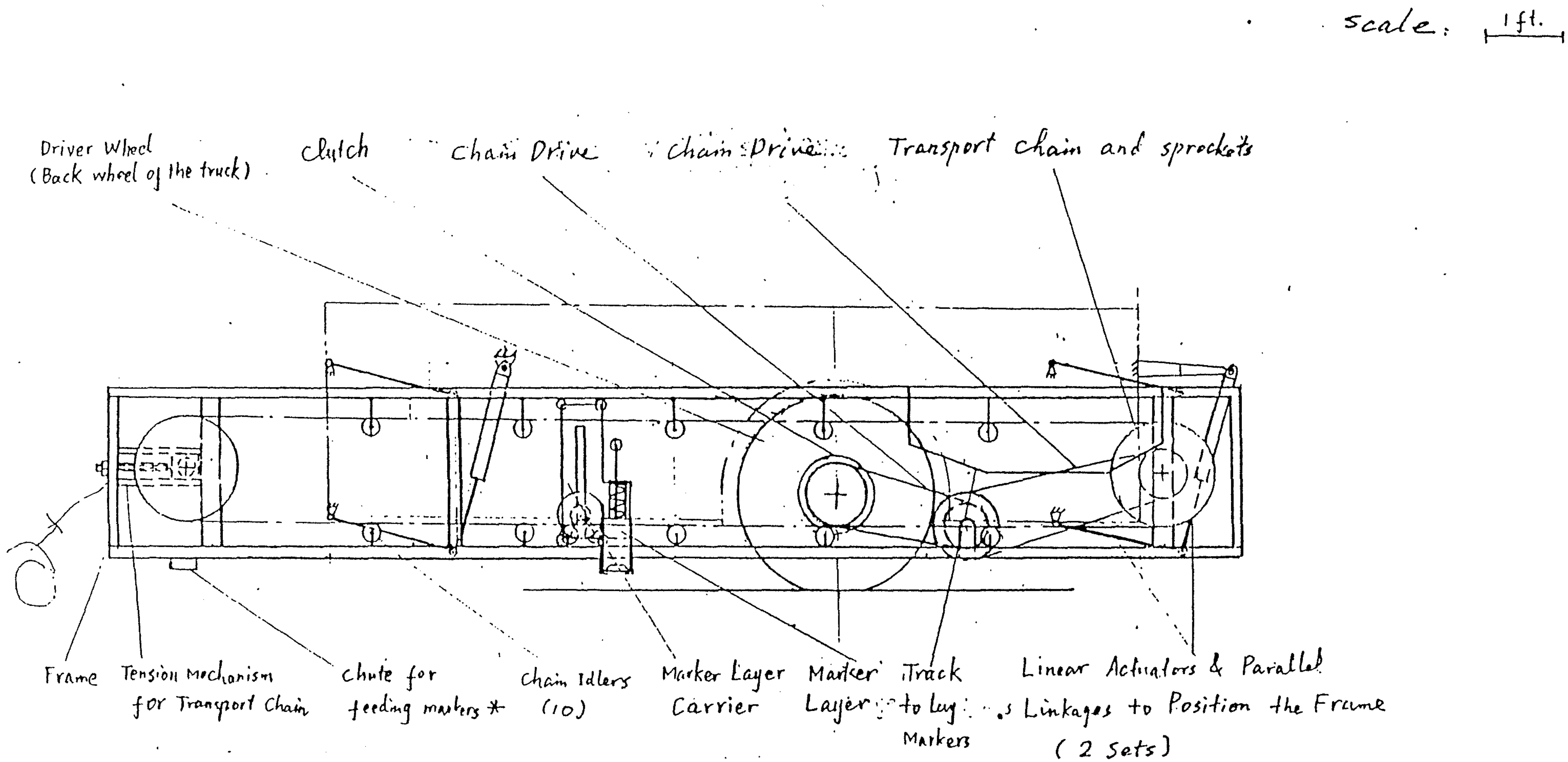


Fig. 4 Alternate modification of Phase I machine.

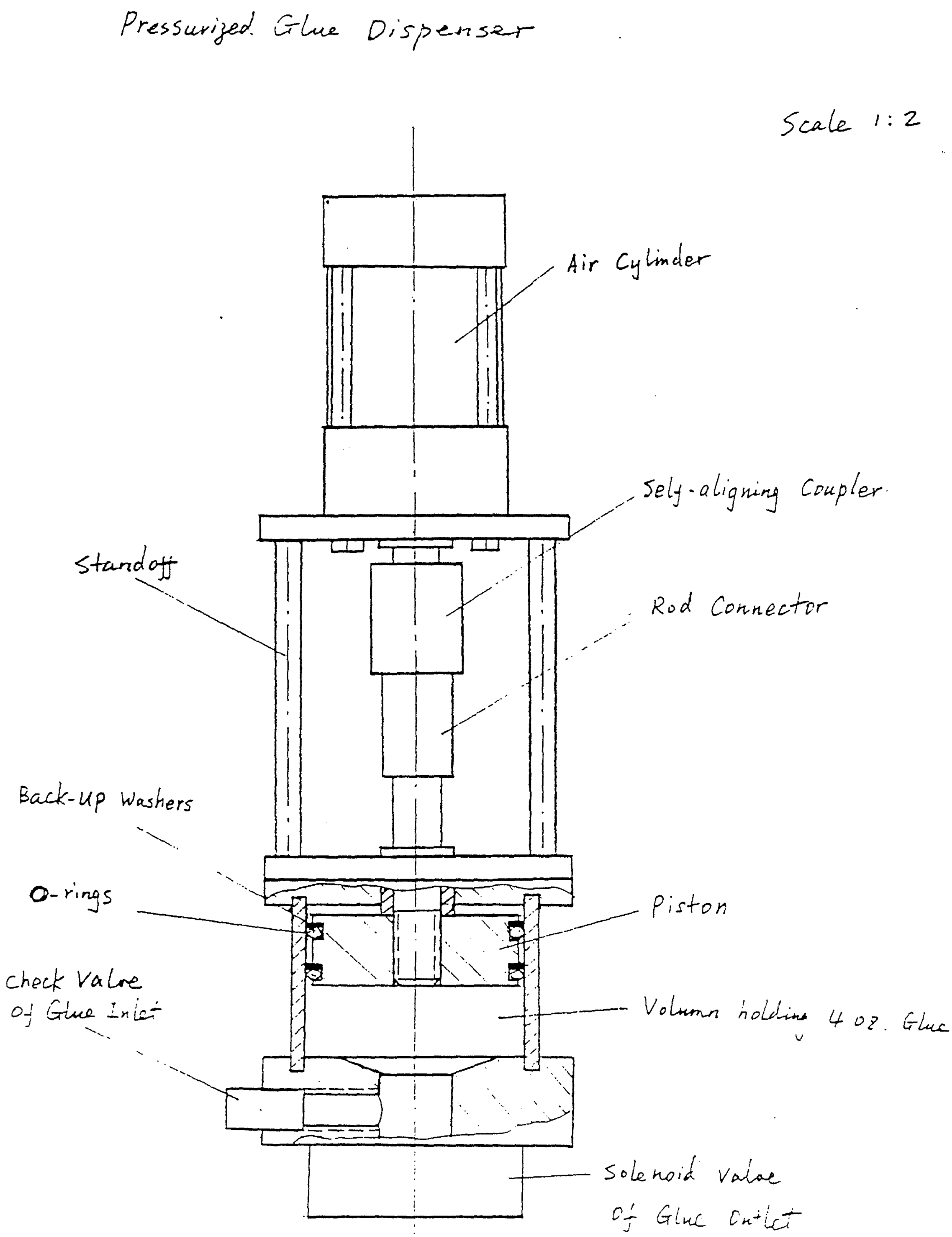


Fig. 5 Pressurized glue dispenser.

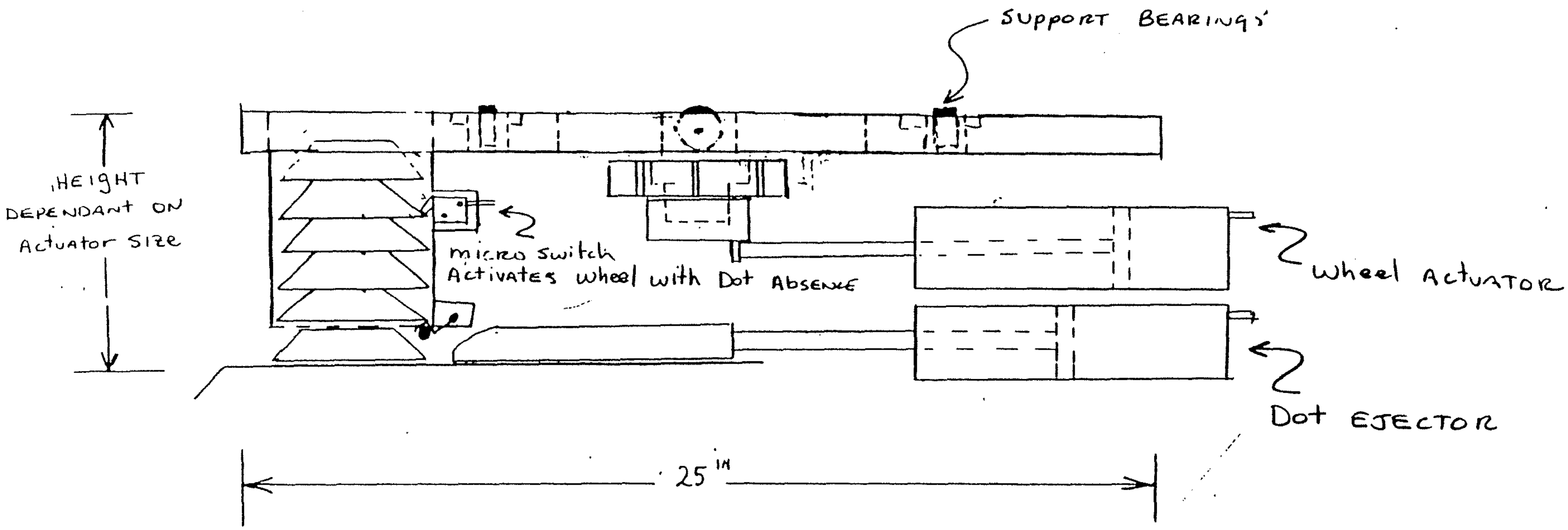


Fig. 6 Dot loading concept.

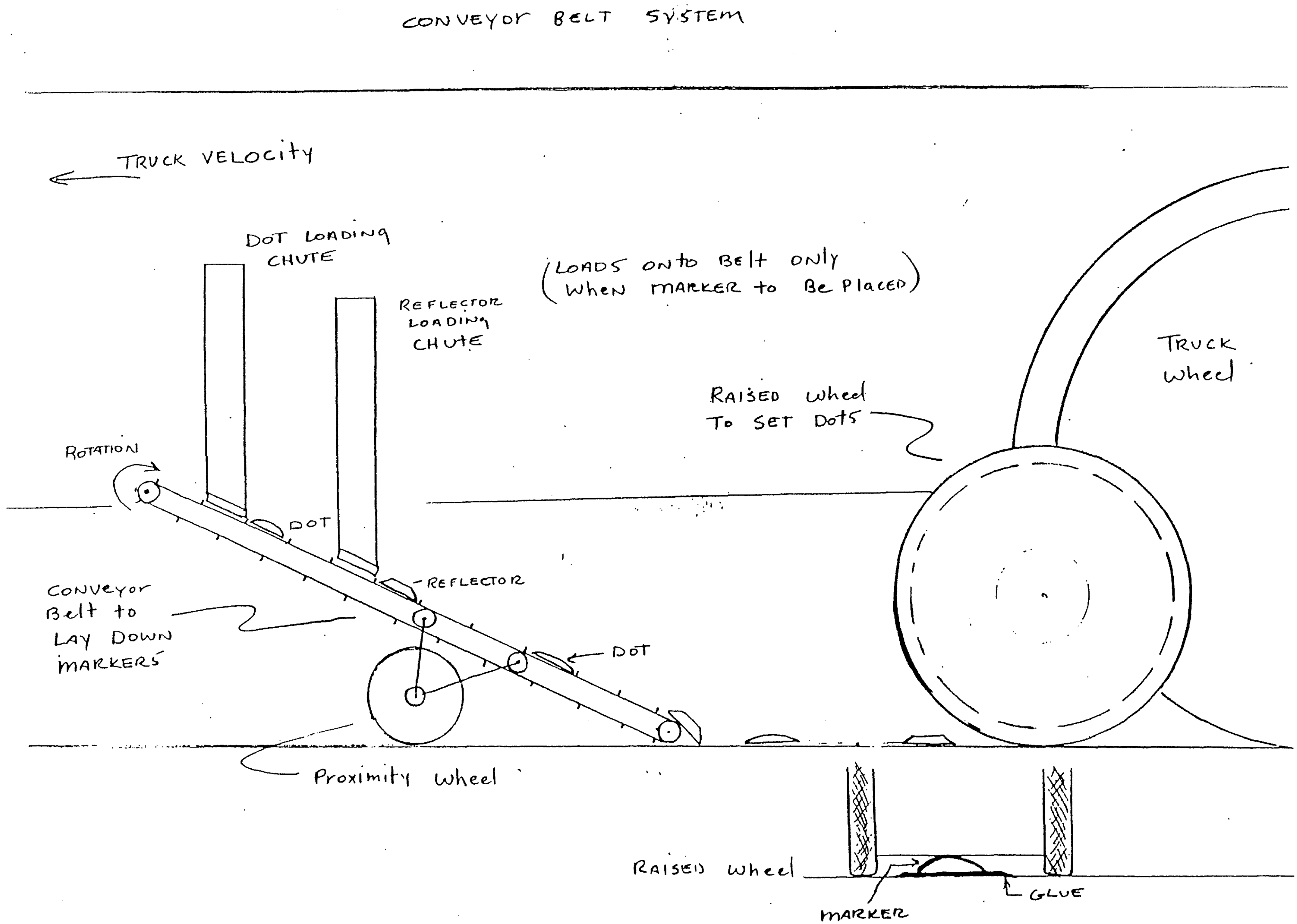


Fig. 7 Conveyor belt concept.

Proposed Belt system.

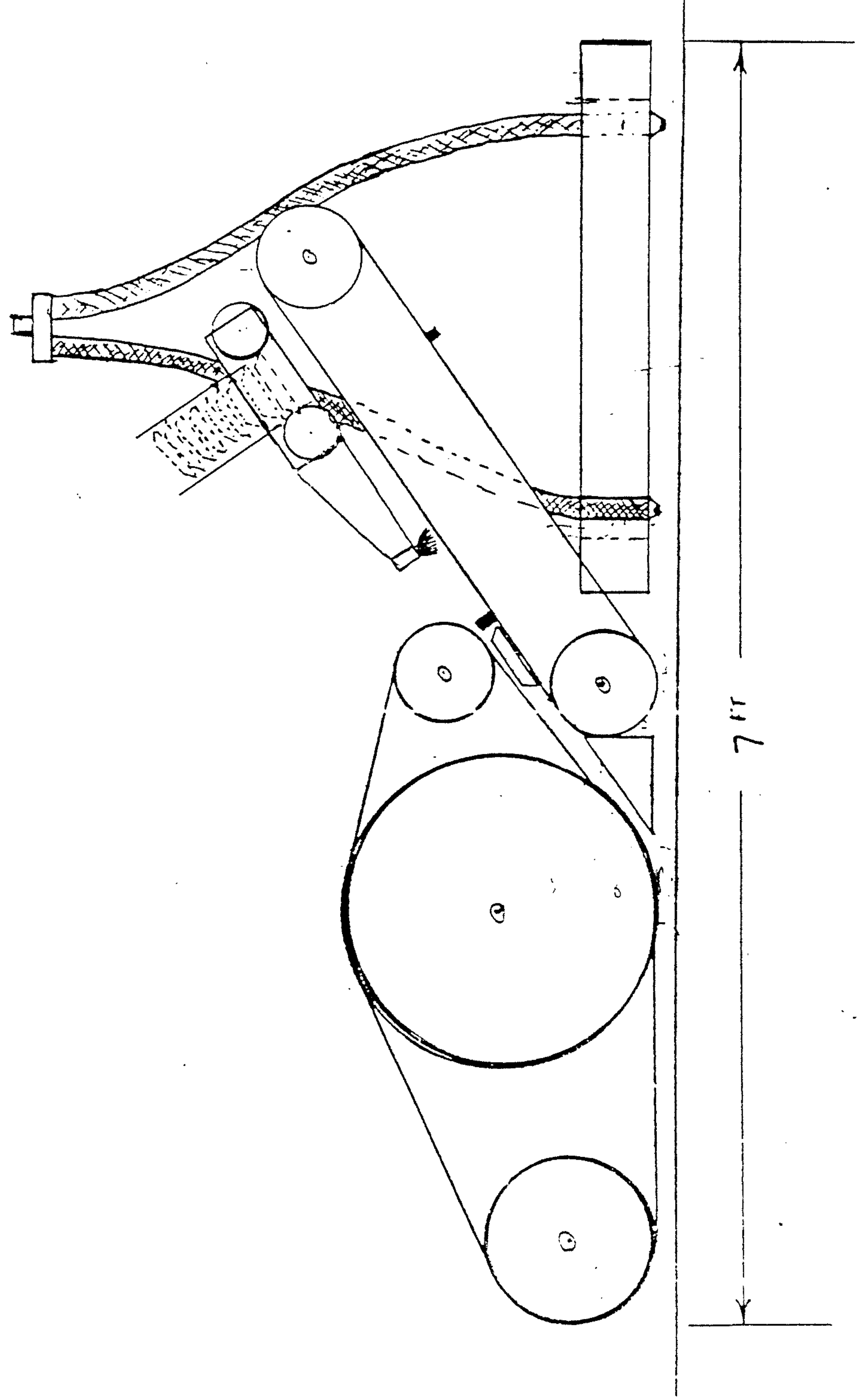


Fig. 8 Proposed belt system.

IDEA III: WHEEL MECHANISM

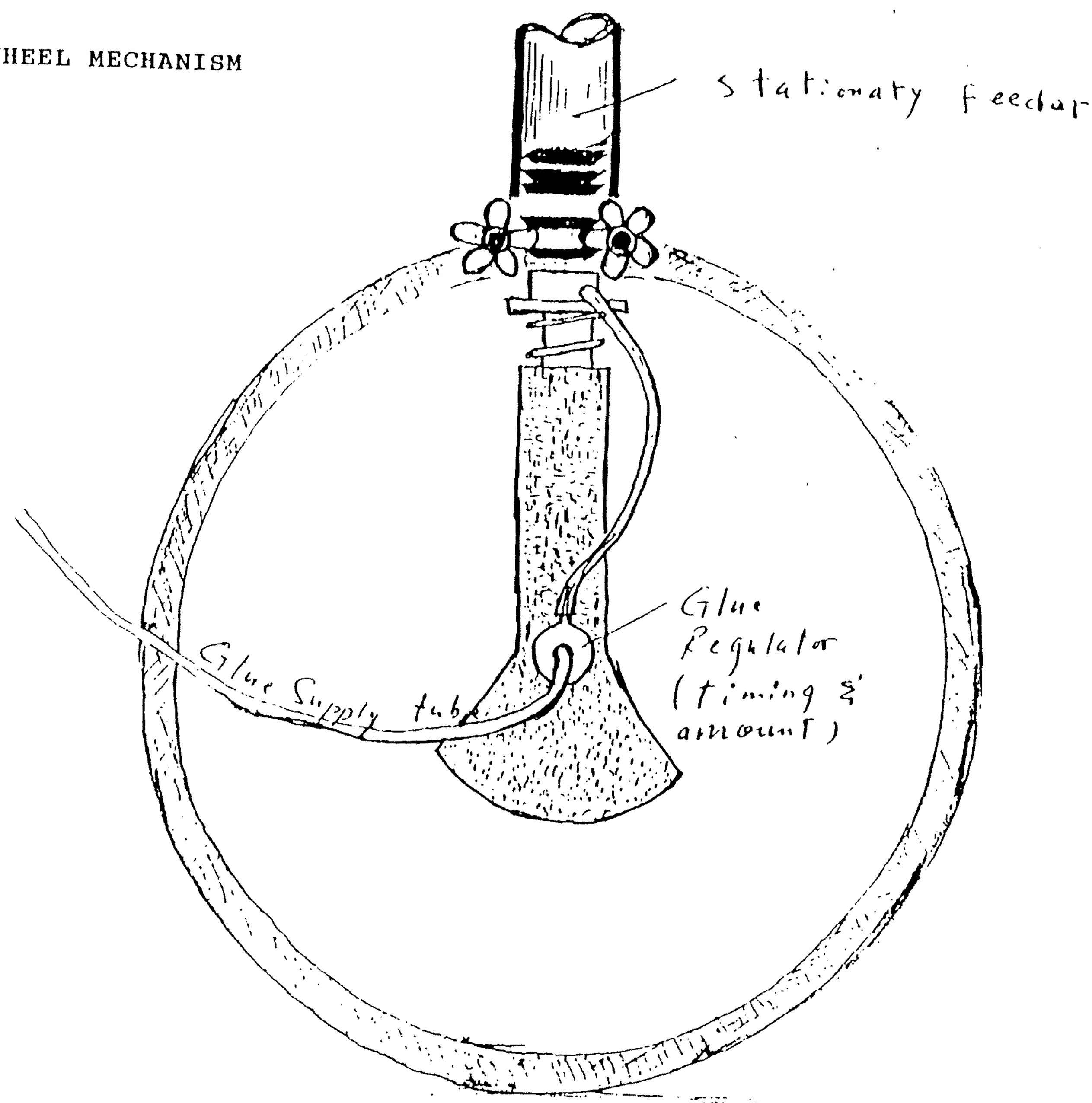


Fig. 9 Wheel mechanism

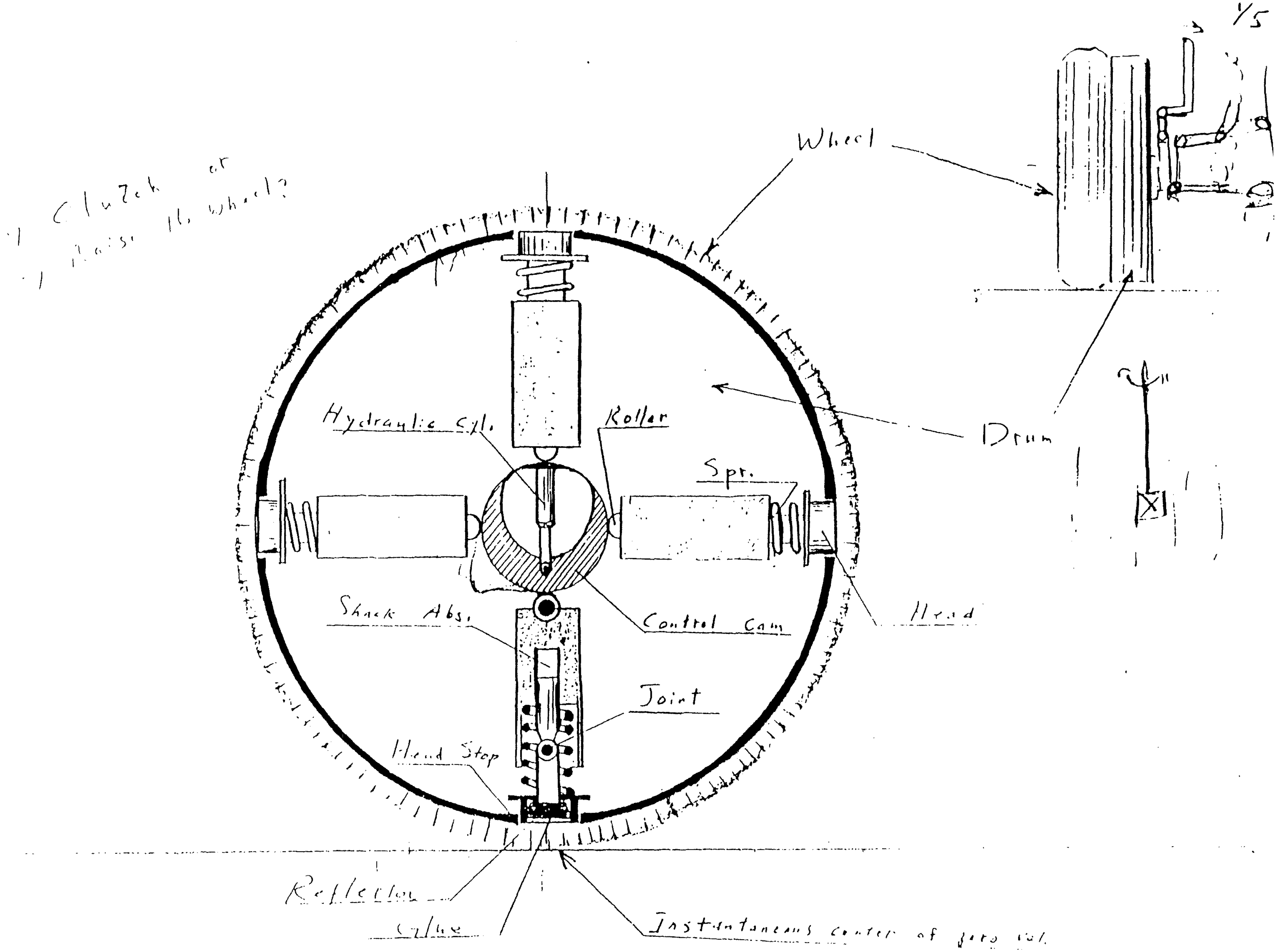


Fig. 10 Wheel mechanism concept II.

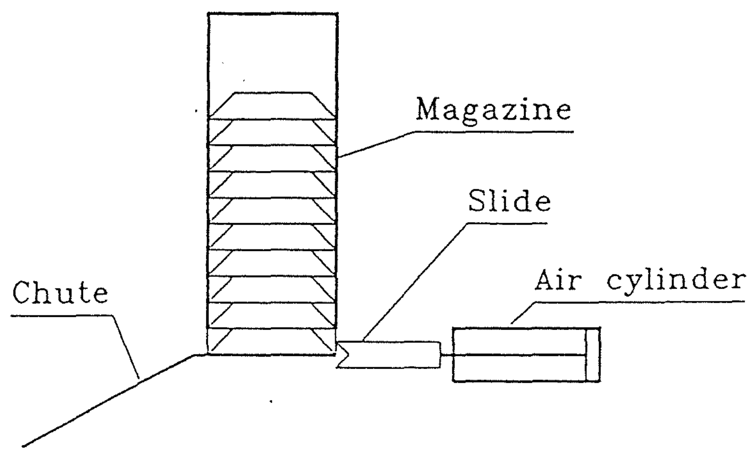


Fig. 1.1 Marker loading mechanism concept I.

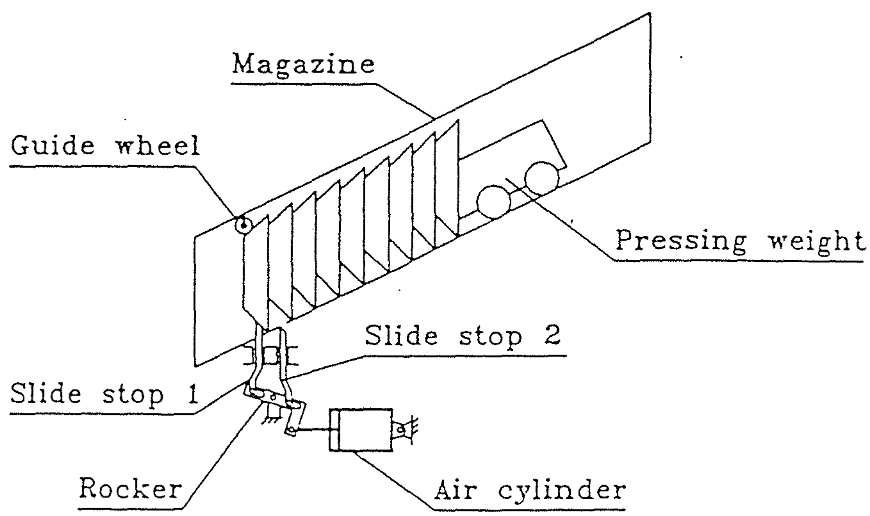


Fig. 1.2 Marker loading mechanism concept II

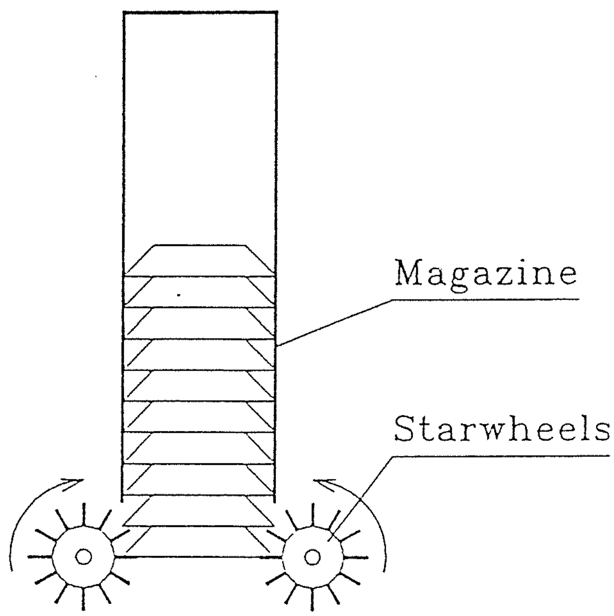


Fig. 1.3 Marker loading mechanism concept III.

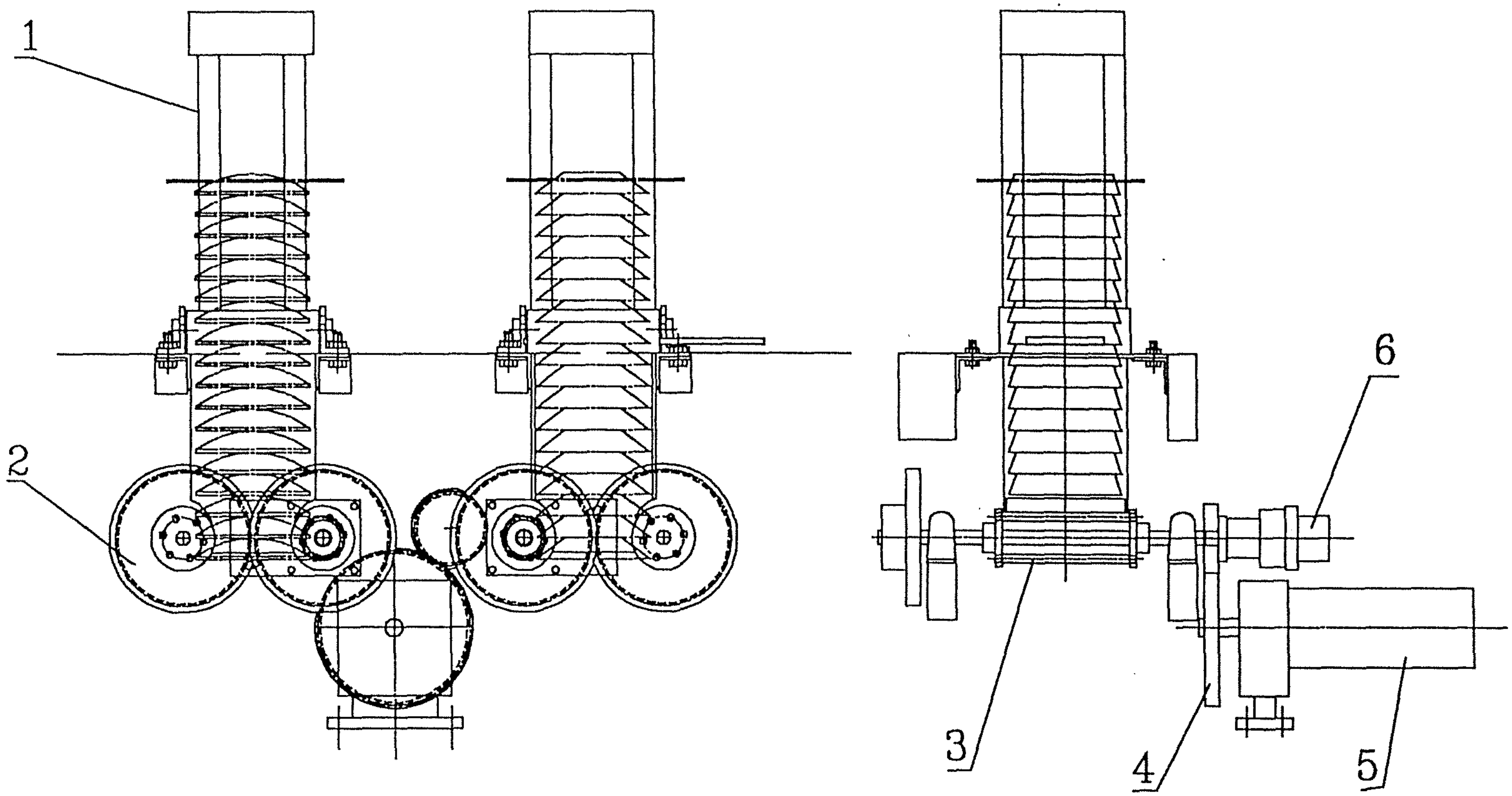


Fig.1.4 marker Loader System

1– Marker storage; 2– Starwheel gears; 3– Starwheels; 4– Gear drive; 5– DC gearmotor; 6– Wrap spring clutch/brakes.

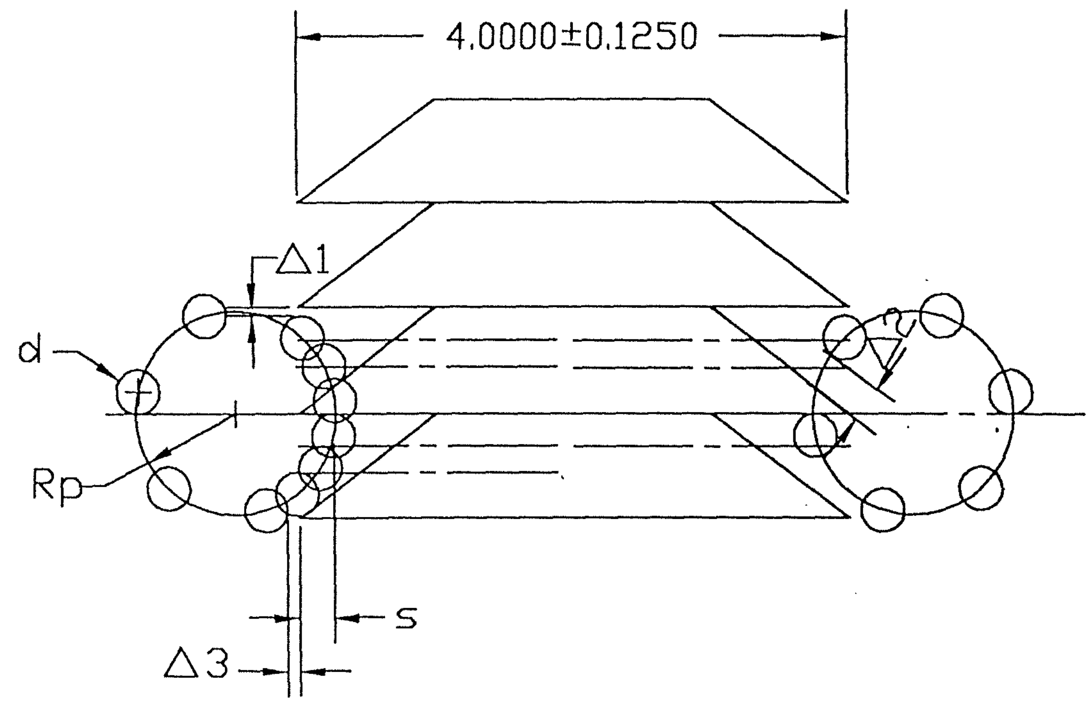


Fig.1.5 Parameters of the starwheel

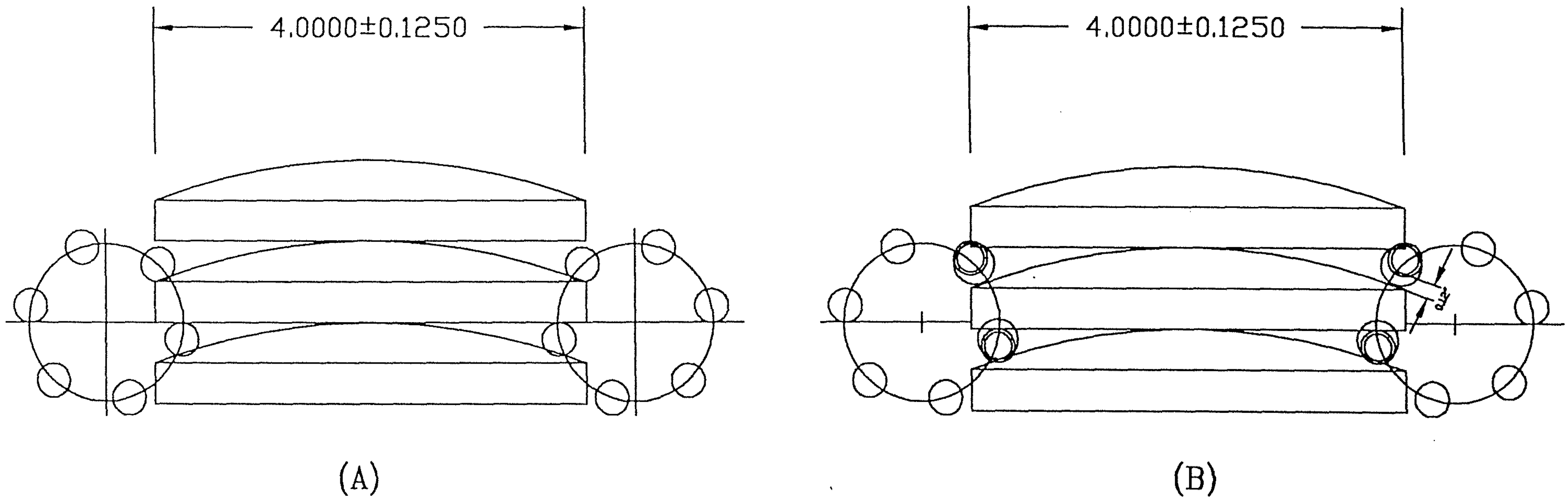


FIG.1.6

(A) There is no clearance between marker face surface and rod.

(B) Possible clearance of 0.12" obtained by taking nylon bush off.

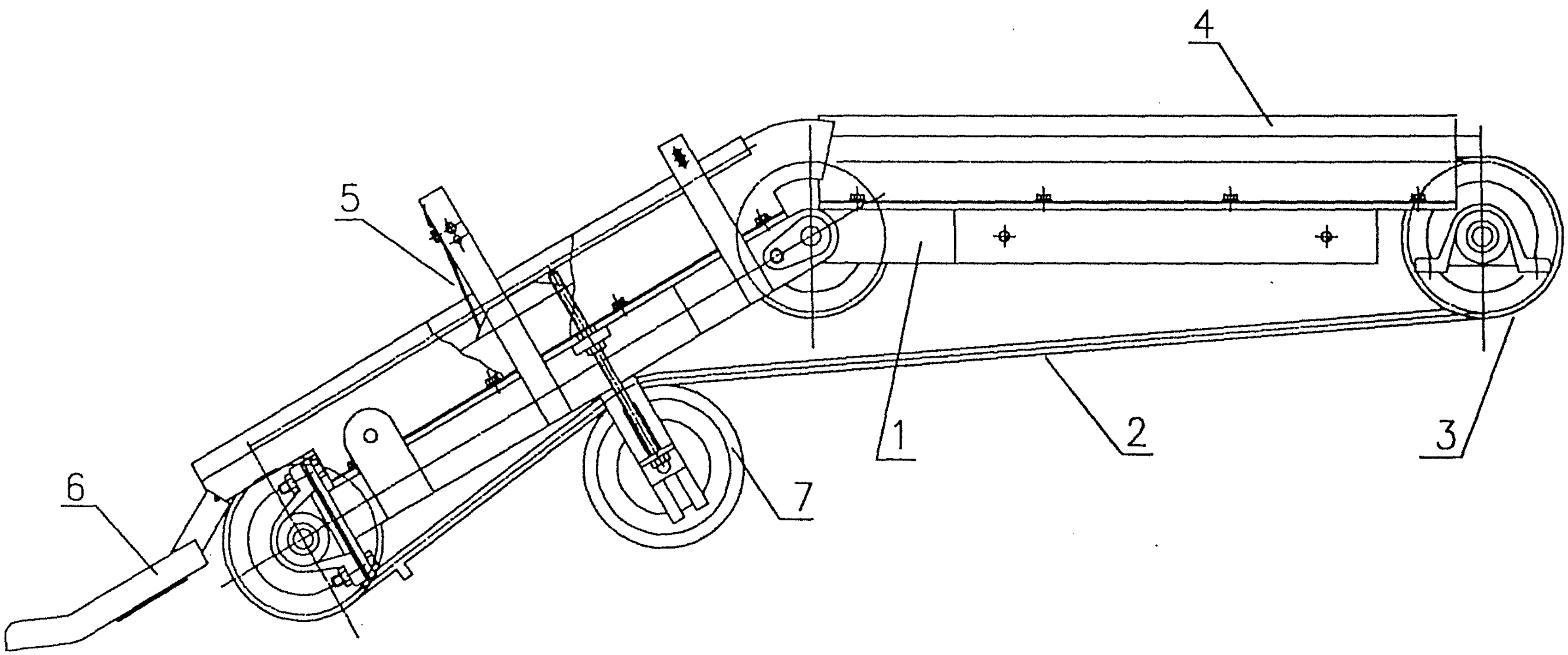


Fig 2.1 Marker Delivery System

1– Frame; 2– Belt; 3– Pulleys; 4– Walls; 5– Stopper; 6– Chute; 7– Tensioner

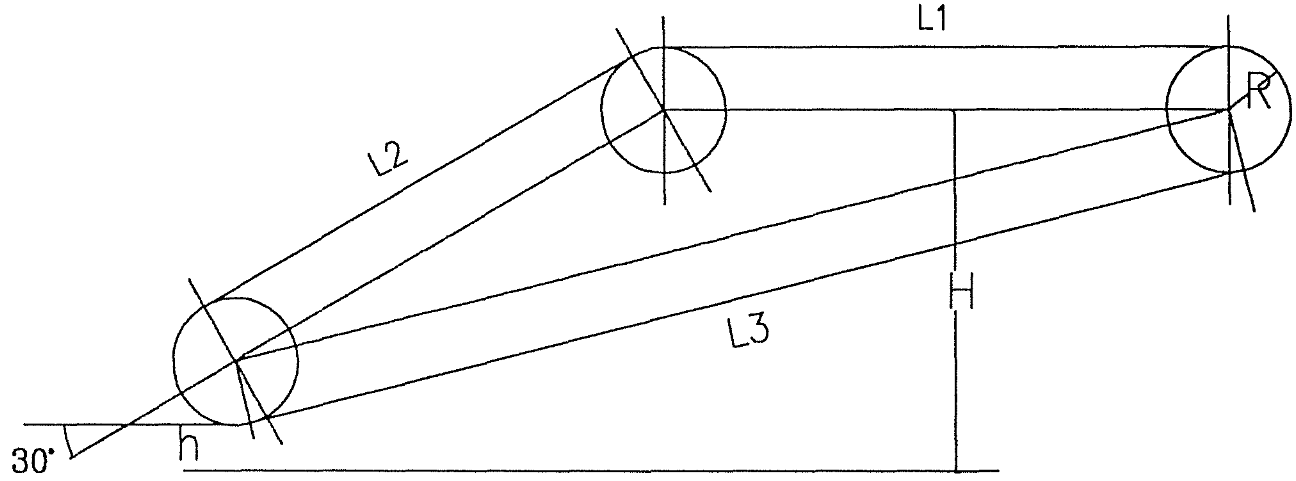


Fig.2.2 Belt configuration

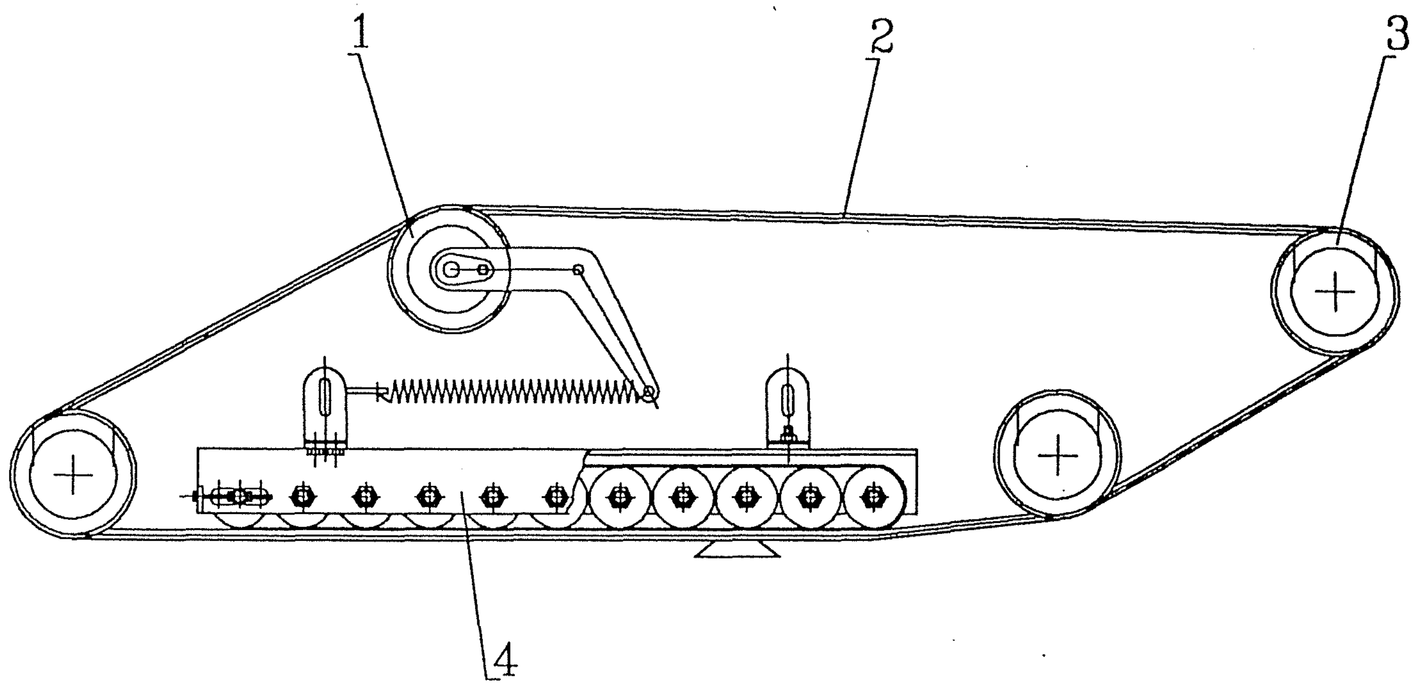
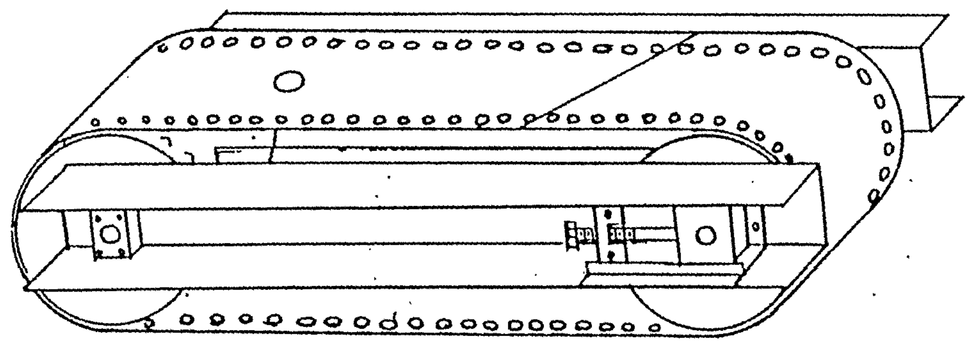


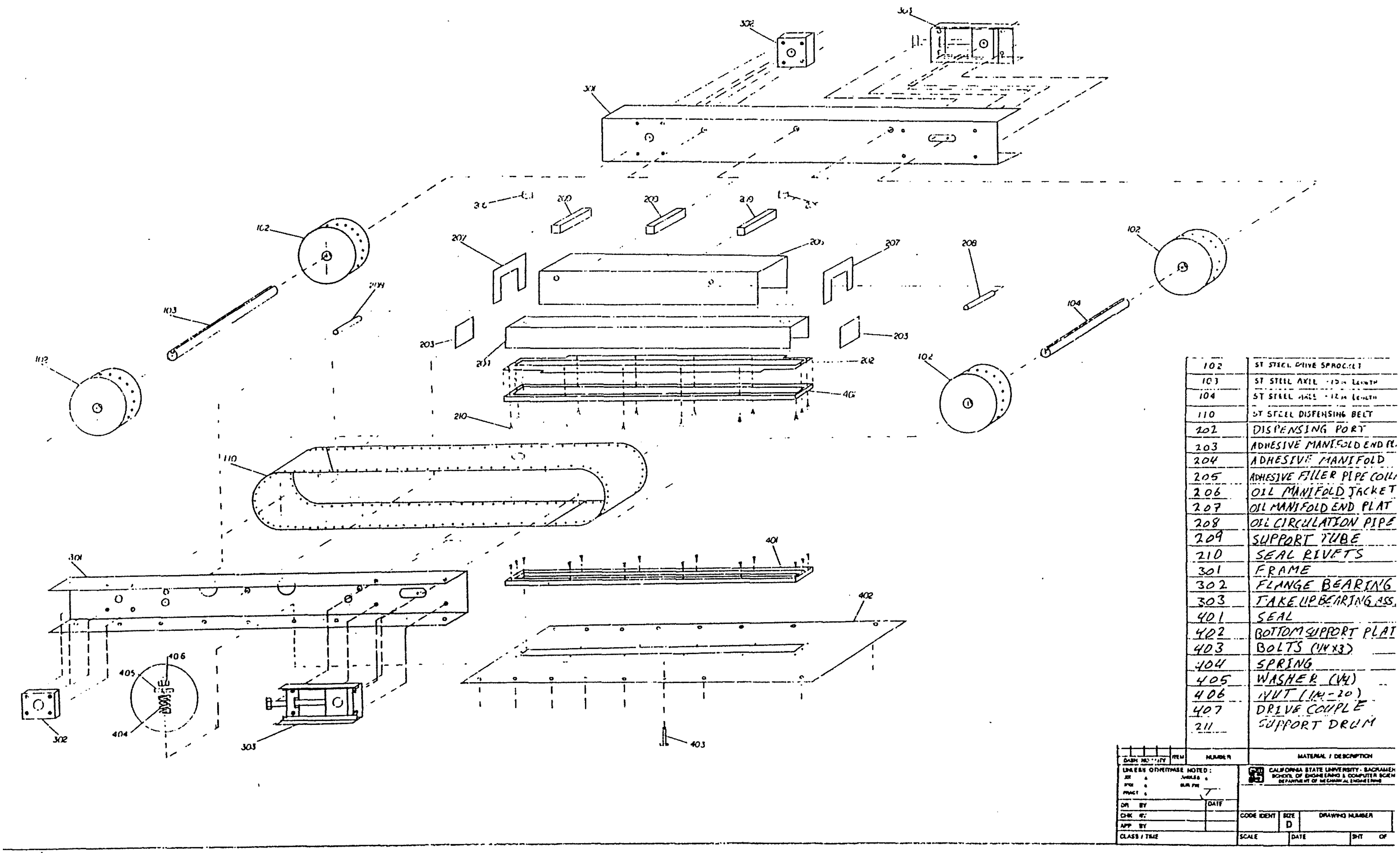
Fig.3.1 Marker Press System

1– Tensioner; 2– Timing belt; 3– Pulleys; 4– Roller press.



ADHESIVE DISPENSER

FIGURE 4.1



Number	Material / Description
102	ST STEEL DRIVE SPROCKET
103	ST STEEL AXLE ·12 in LENGTH
104	ST STEEL AXLE ·12 in LENGTH
110	ST STEEL DISPENSING BELT
202	DISPENSING PORT
203	ADHESIVE MANIFOLD END PL.
204	ADHESIVE MANIFOLD
205	ADHESIVE FILLER PIPE COLL.
206	OIL MANIFOLD JACKET
207	OIL MANIFOLD END PLAT
208	OIL CIRCULATION PIPE
209	SUPPORT TUBE
210	SEAL RIVETS
301	FRAME
302	FLANGE BEARING
303	TAKE UP BEARING ASS.
401	SEAL
402	BOTTOM SUPPORT PLAT
403	BOLTS (1/4 X 3)
404	SPRING
405	WASHER (1/4)
406	NUT (1/4-20)
407	DRIVE COUPLE
211	SUPPORT DRUM

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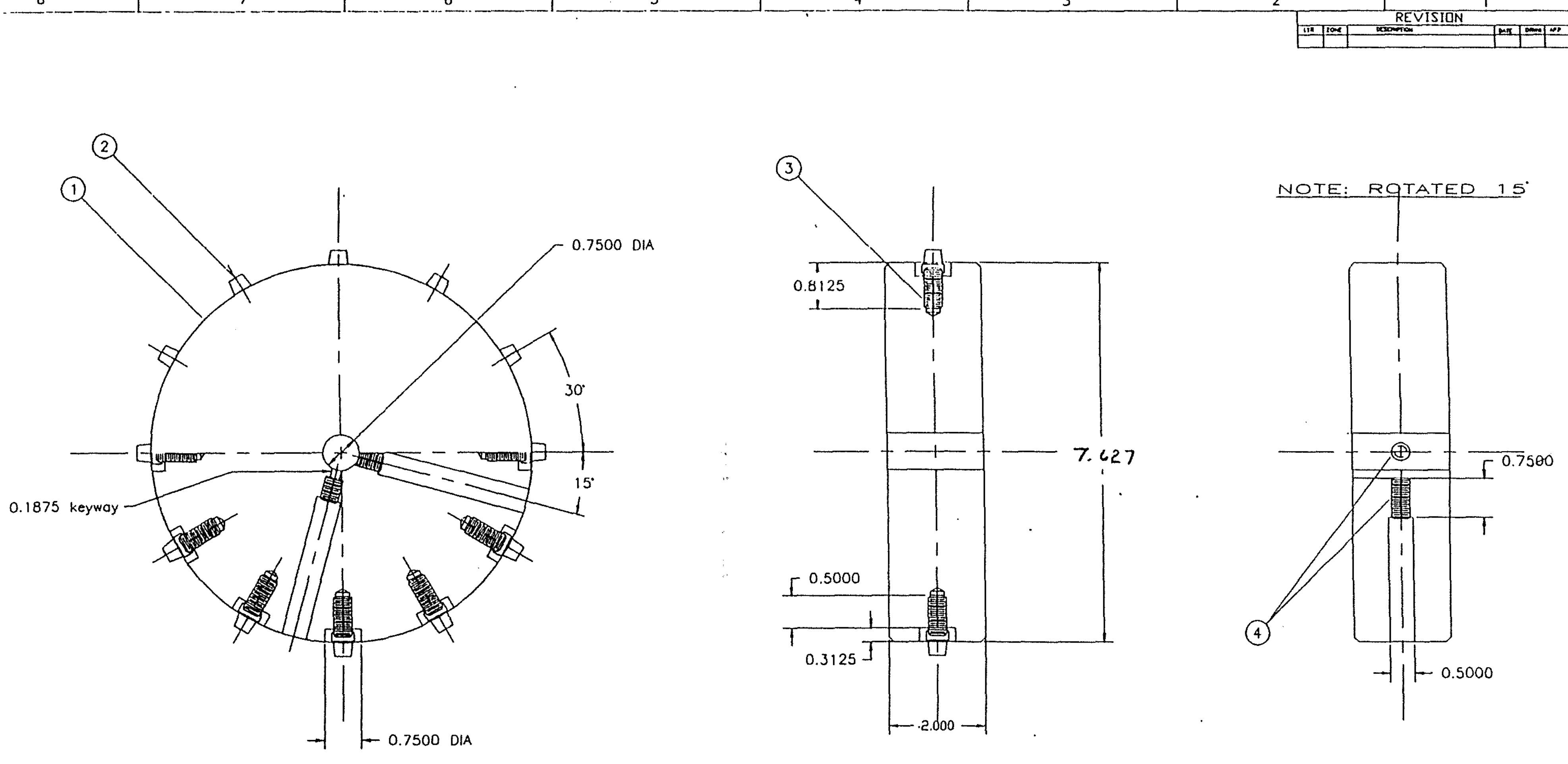
SCHOOL OF ENGINEERING & COMPUTER SCIENCE
DEPARTMENT OF MECHANICAL ENGINEERING

UNLESS OTHERWISE NOTED: | DR BY | CHK BY | APP BY | DATE | CLASS / TIME | CODE IDENT | SIZE D | DRAWING NUMBER | SCALE | DATE | SHT OF

FIGURE 4.2 Exploded view



ITEM NO.	PART / ID NO.	NOMENCLATURE / DESCRIPTION	MATERIAL / SPECIFICATION	QTY REQD
4	5061K11	Set Screw	3/8 DIA- 3/4 length	2
3	5061K11	Stud	3/8 DIA- 3/4 length	12
2	91376A622	Tubing Flare Nut	3/16 DIA- short length	12
1		Pulley	Aluminum	1

PART LIST

UNIVERSITY OF CALIFORNIA, DAVIS
MECHANICAL ENGINEERING DEPARTMENT
ADHESIVE TEST DESIGN
Sprocket

FIGURE 4.3 Belt drive sprocket

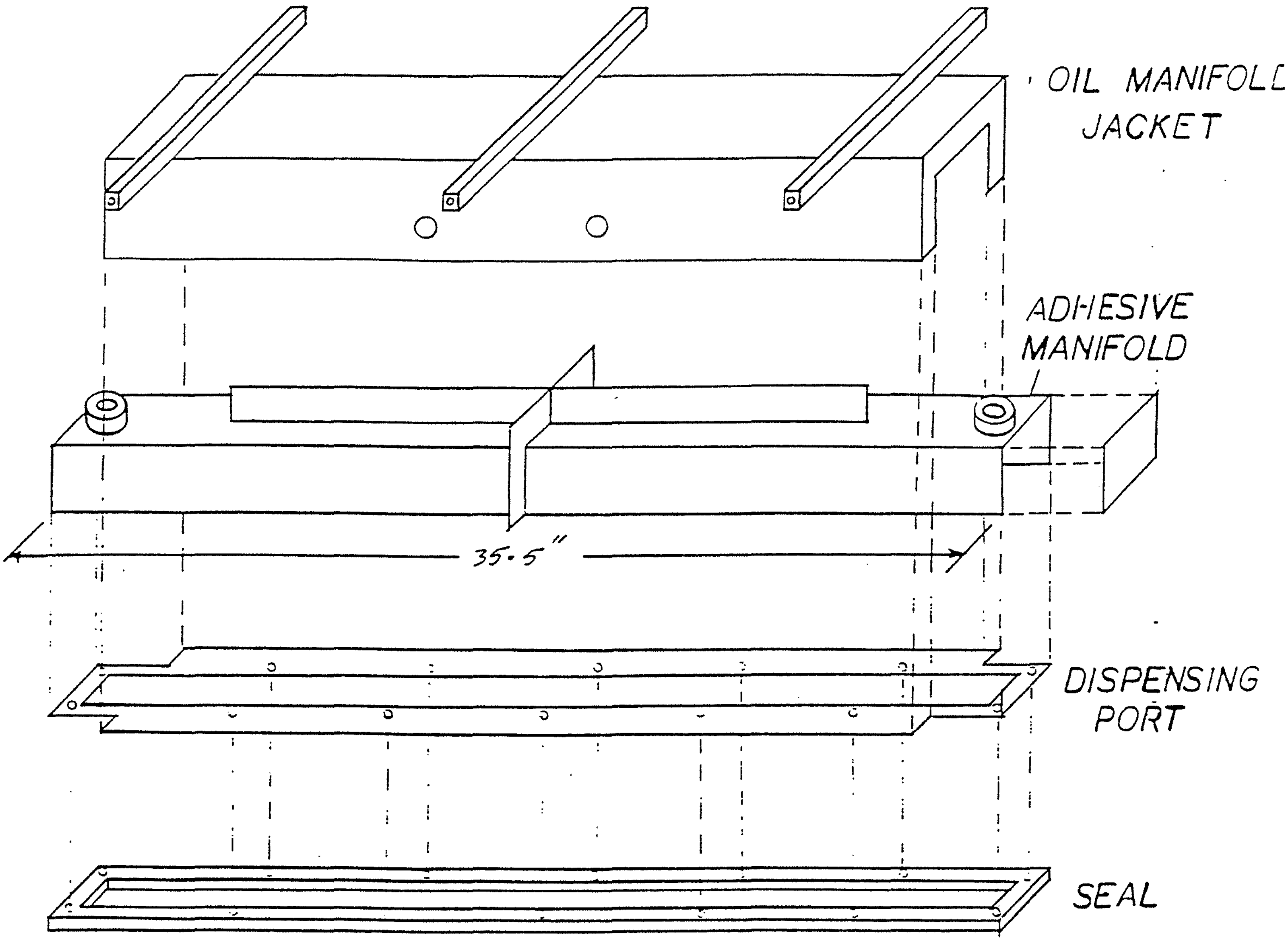


FIGURE 4.4 Adhesive manifold

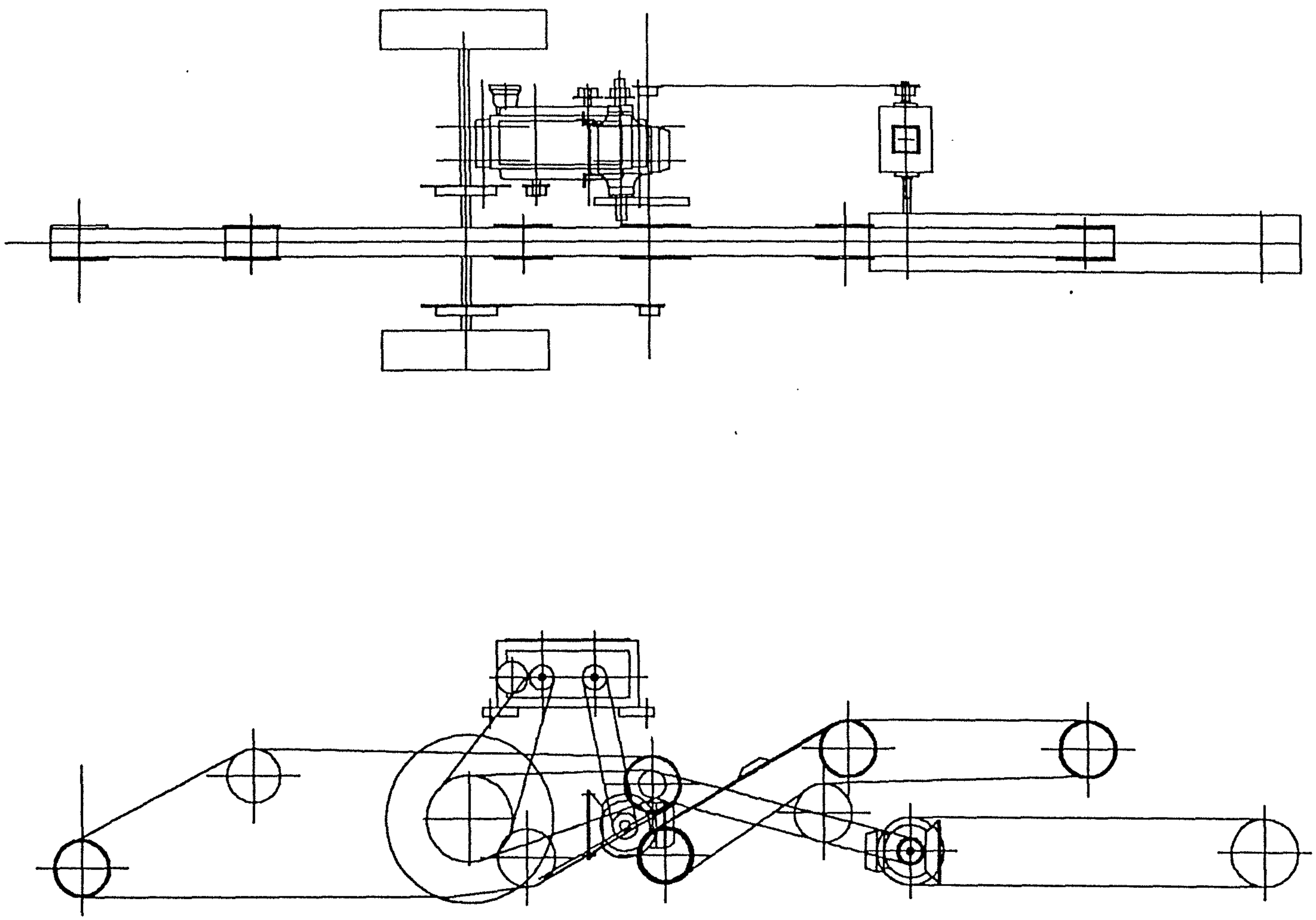


Fig.5.1 Drive Synchronization System

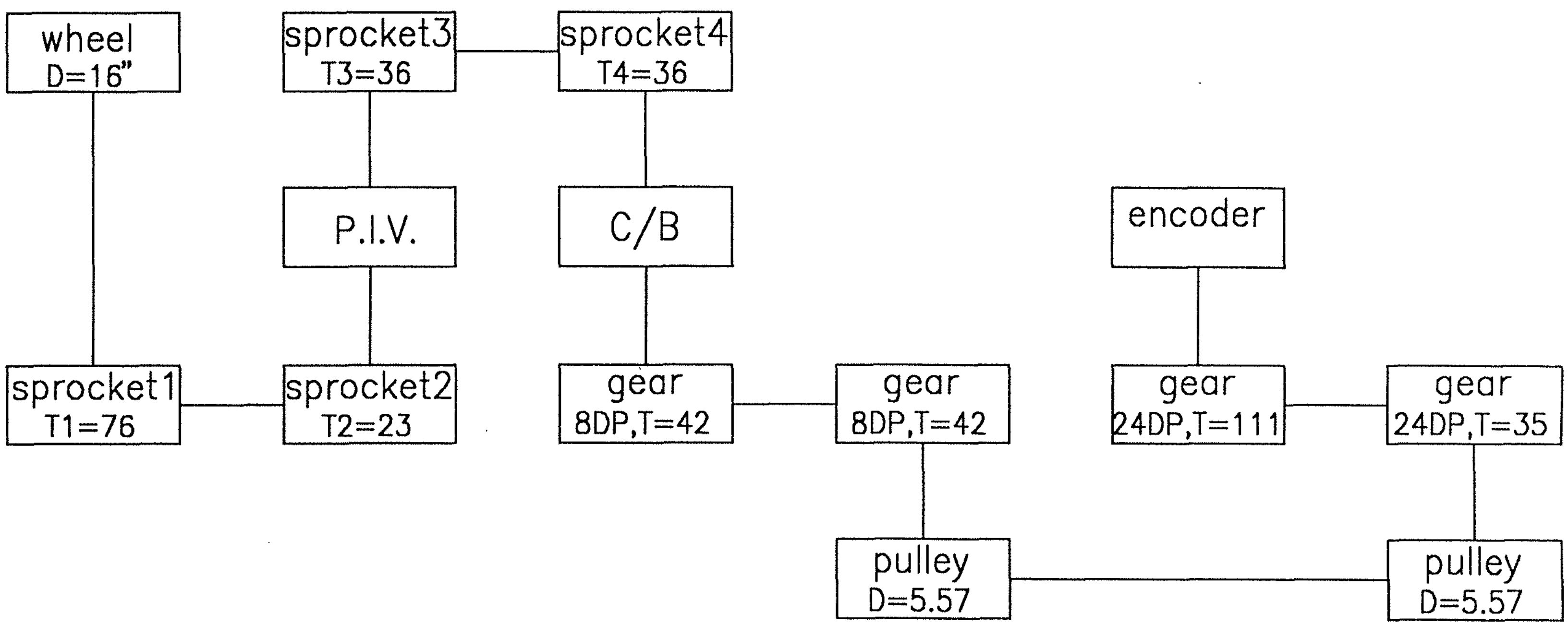


Fig. 5.2a drive path for marker delivery system

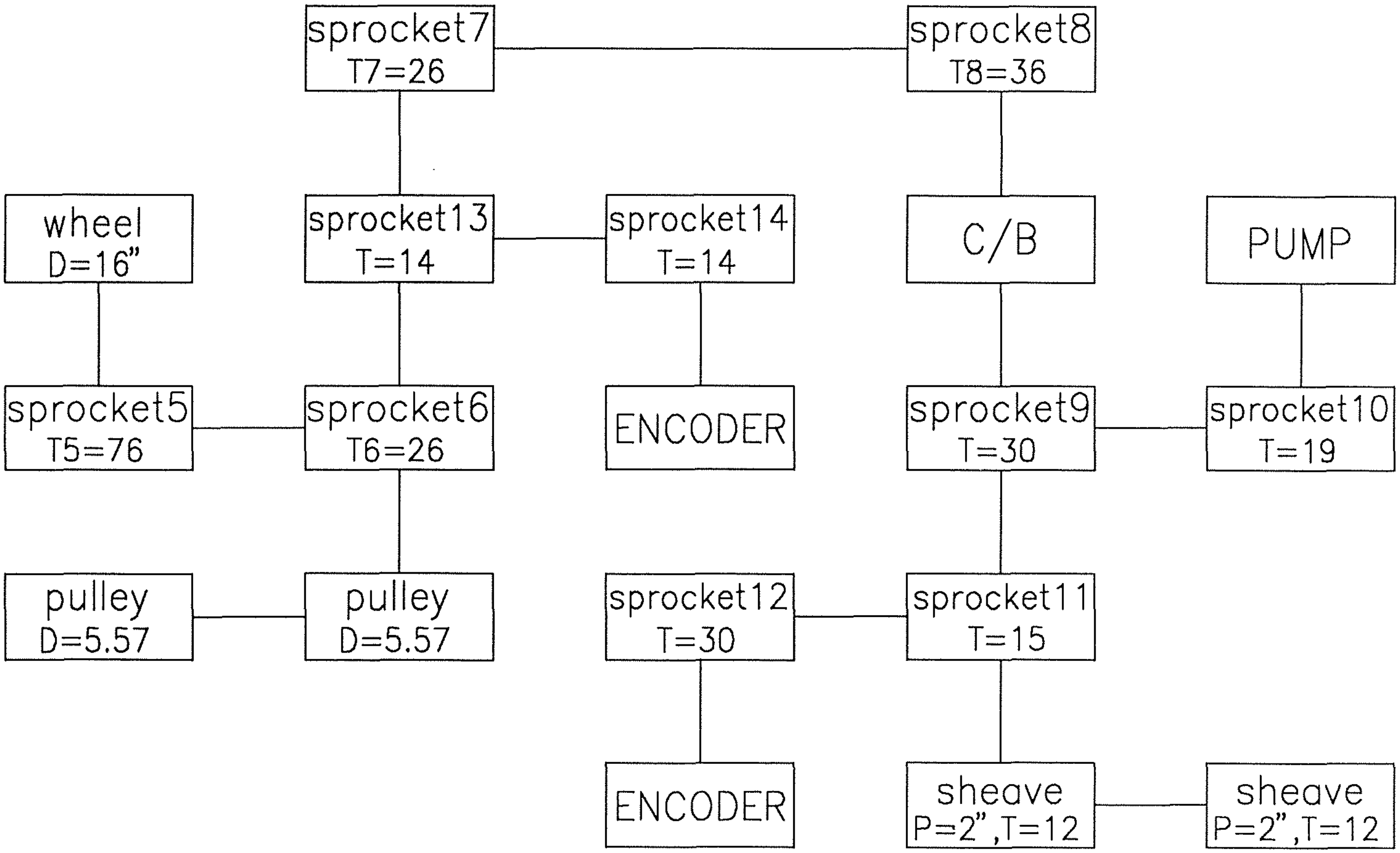


Fig.5.2b Drive path for press and adhesive belts

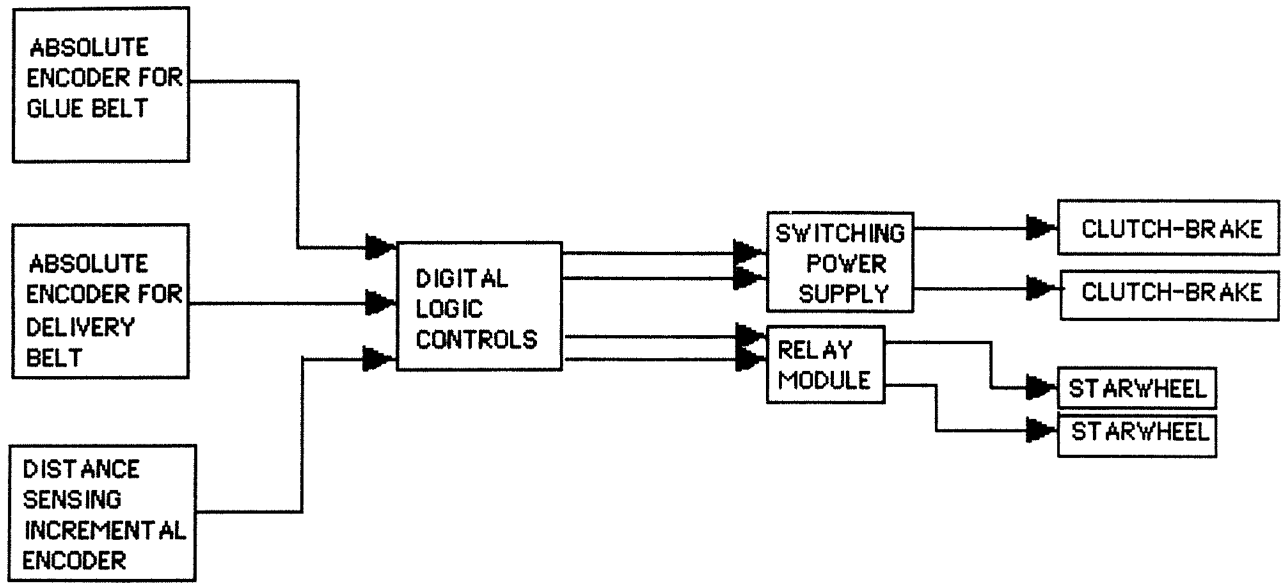


FIG. 6.1

BASIC CIRCUIT LAYOUT

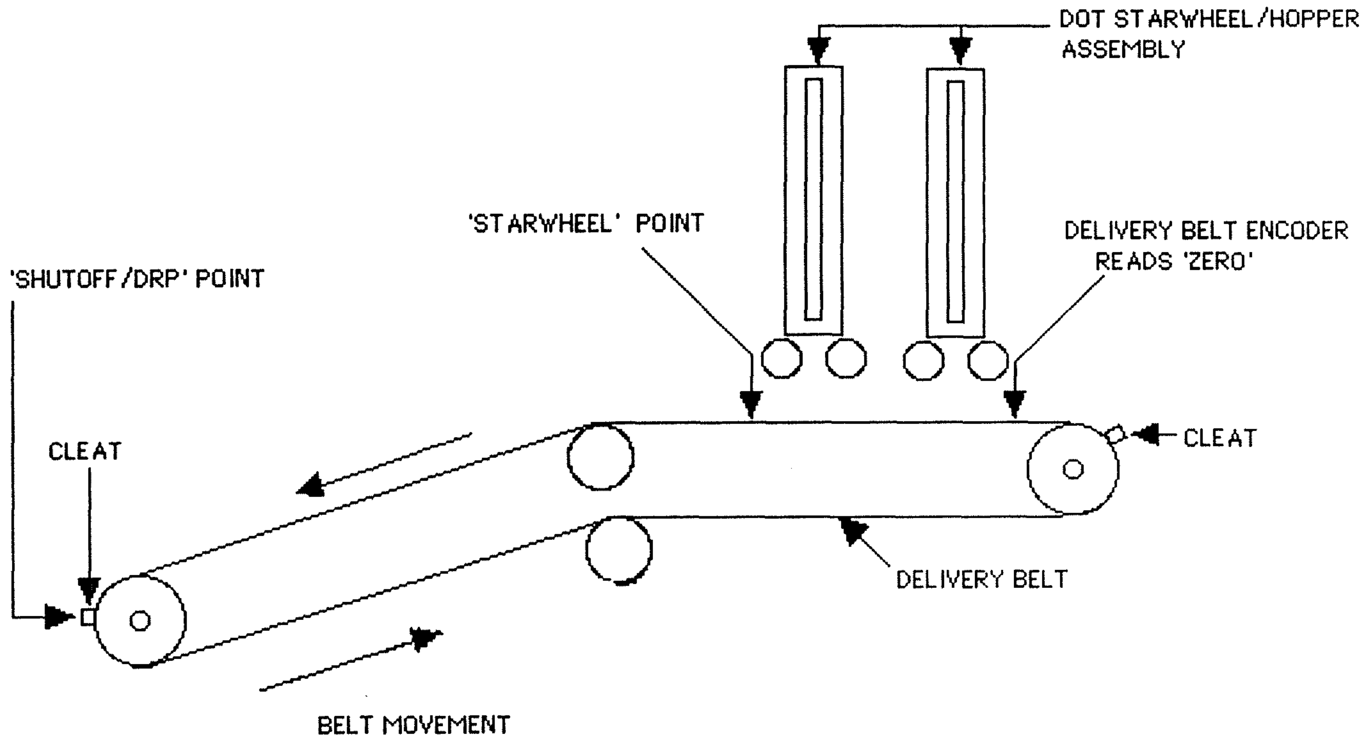


Fig. 6.2 Delivery belt diagram pertaining to the control logic.

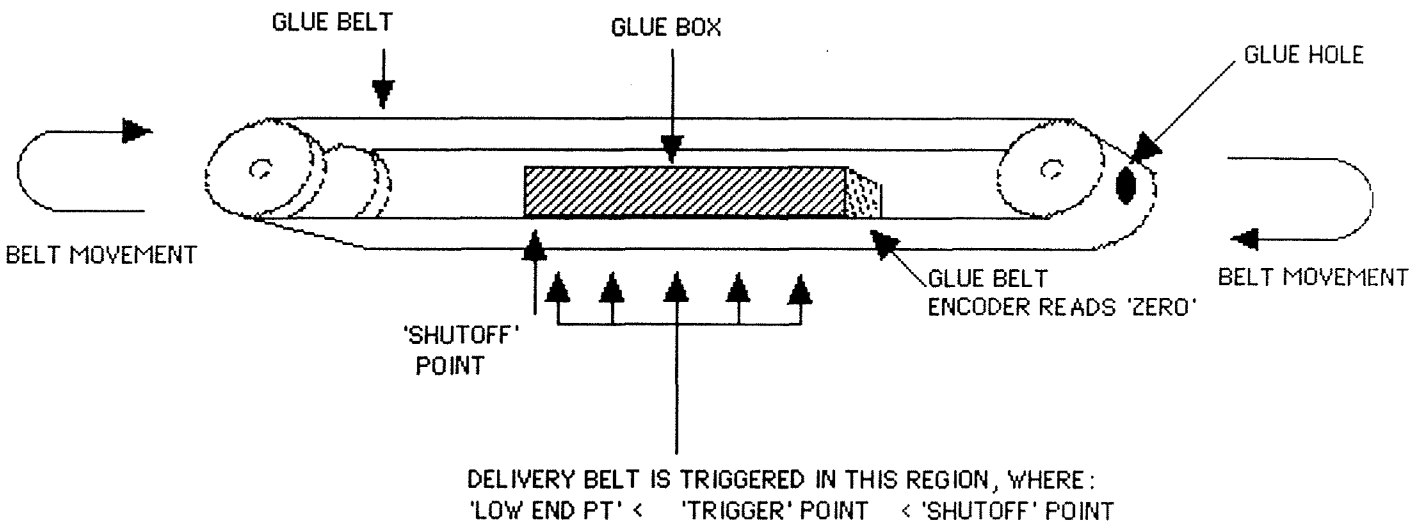


Fig. 6.3 Glue belt diagram pertaining to the control logic.

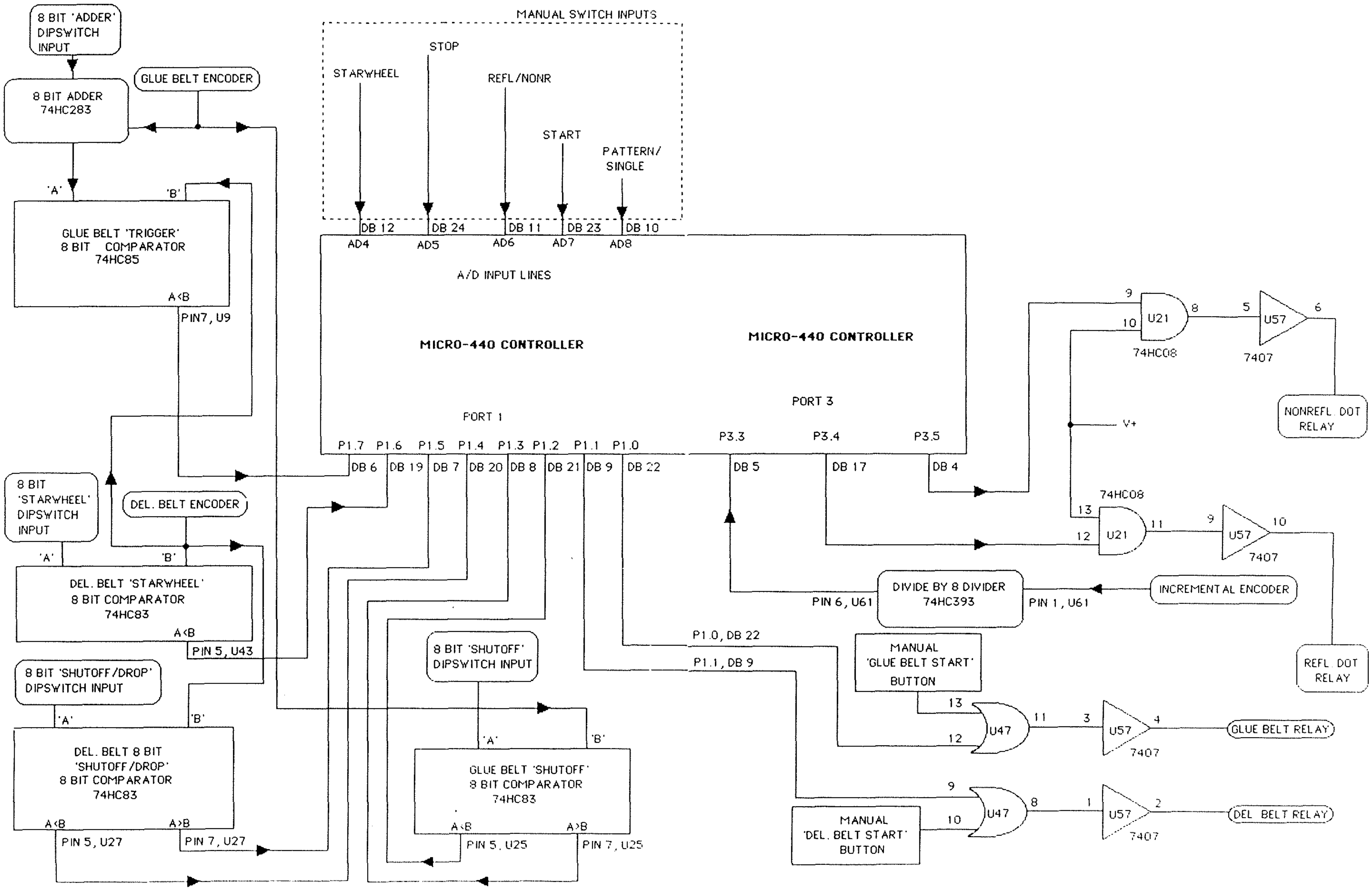


Fig. 6.4 Circuit layout using Micro-440 controller.

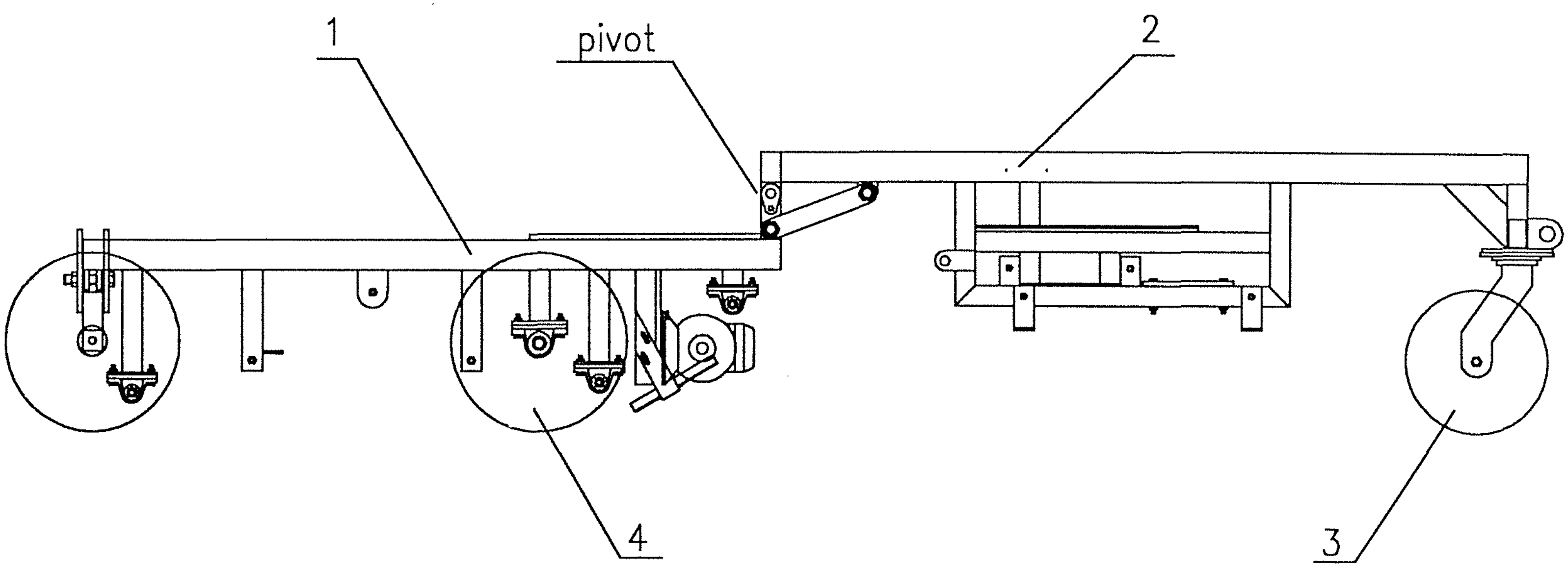


Fig.7.1 Main Frame

1– Low frame; 2– High frame; 3–Casters; 4– Wheels.

APPENDIX B

TABLES

TABLE 8.1

Temperature	Shampoo	Sand
66°F	16 oz.	0 cup
70	16	1/4
76	16	1/2
80	16	3/4
83	16	1
86	16	1 1/4

TABLE 8.2

RUN	TIME (sec)	VELOCITY (mph)	HOLE DIA. (in)	VOL. (ml)	VOL. (oz)	SPEED SETTING	GLUE DIST. FROM TOP
1	0.146	9.34	1.50	42	1.24	64%	- -
2	0.146	9.34	1.25	35	1.03	64	- -
3	0.200	6.82	1.50	60	1.77	55	- -
4	0.200	6.82	1.25	50	1.48	55	- -
5	- -	- -	3.5x1.5	120	3.55	64	1.75
6	0.142	9.60	3.5x1.5	125	3.69	64	1.88
7	0.156	8.74	2.0x1.5	80	2.37	64	2.00
8	0.148	9.21	2.5x1.5	100	2.96	64	2.07

TABLE 8.3

R=reflector D=dot

Static wt. (lbs)	Marker Type	Bitumen Thickness (in.)	Displacement (in.°)
0	R	5/32	N/A
0	R	6/32	N/A
10	R	4/32	N/A
30	R	3/32	N/A
100	R	3/32	N/A
160	R	3/32	N/A
160	R	3/32	N/A
Rolling Wheel			
(25 lbs, 20 psi, 3/4" Raised)			
	R	4/32	0,0
	R	4/32	0,0
	D	6/32	0,0
(35 lbs, 20 psi, 3/4" Raised)			
	R	4/32	0,0
	D	6/32	0,0
(25 lbs, 20 psi, 1/8" Raised)			
	R	4/32	1/4,<5
	R	4/32	1/4,<5
	R	4/32	1/4,<5
	D	6/32	0,0
Deflated Tire			
	R	5/32	0,0

APPENDIX C

CALCULATIONS

Table of Contents

APPENDIX C - 1

Size Selection of Wrap Spring Clutch/brake

1) Torque requirement

The size of wrap spring clutch/brake was determined based on the total torque requirement.

$$T_{req} = WR^2 \text{ X } N/3700t - T_{fri}$$

where T_{req} is the torque required to operate the clutch/brake in lbs.in, N is shaft speed at clutch/brake location, t is the time allowed for disengagement, WR^2 is total load inertia for the clutch/brake system, Tfri is the friction torque.

In calculating total load inertia, the components must be taken into account for are: two shafts, two starwheels which include four plates and two rods, a pair of gears.

For the cylindrical solid body rotating about its own axis, its load inertia is:

$$WR^2 = 3.14r^4lG/2$$

Where r and l are the radius and length (or thickness) of the cylinder respectively, and G is the specific gravity of the body, $G = 0.284 \text{ lb/in}^3$.

For the two shafts, d = 0.5", l_1 = 16" and l_2 = 11"

$$WR^2_{shaft} = 3.14\ (0.5/2)^4\ (16+11) \times 0.284/2 = 0.047 \text{ lb.in}^2$$

For four starwheel plates with projection,

$$d_1 = 2.25\text{"}, l_1 = 0.25\text{" and } d_2 = 1.125\text{"}, l_2 = 0.5\text{"}$$

$$WR^2_{plate} = WR^2_{plate} + WR^2_{proj}$$

$$= 3.14\ [\ (2.25/2)^4 \times 0.25 + (1.125/2)^4 \times 0.5] \times 0.284 \times 4/2$$

$$= 0.80 \text{ lb.in}^2$$

In each starwheel, six rods rotate about the axis O of the starwheel. This can be considered as a hollow cylinder rotating about its own axis O. As previous designed, pitch radius r_p = 0.725", rod diameter d_{rod} = 0.313", rod length l = 4.5"

$$r_1 = r_p + 0.5 \times drod = 0.88\text{"}$$

$$r_2 = r_p - 0.5 \times drod = 0.57\text{"}$$

$$WR^2_{rod} = (WR^2_{r1} - WR^2_{r2})\ (6d/(2 \times 3.14r_p) \times 2$$

$$= (r^4_1 - r^4_2)\ 3dlG/r_p = 0.82 \text{ lb.in}^2$$

For the pair of the gears, D_p = 4.8", l_1 = 0.5" and D_{proj} = 2", l_2 = 0.75"

$$WR^2_{gear} = WR^2_{gear} + WR^2_{proj} = 15.46 \text{ lb.in}^2$$

Total load inertia

$$WR^2_{total} = WR^2_{shft} + WR^2_{plate} + WR^2_{rod} + WR^2_{gear}$$

$$WR^2_{total} = 17.13 \text{ lb.in}^2$$

Average torque required

$$T_{req} = WR^2 \text{ X } N/3700t - T_{fri}$$

where N = 68 rpm according to the motor selected and drive train ratio designed which is 1: 2, t = 0.0015 sec. for brake based on the manufacture data, Tfri is friction torque necessary to overcome static friction and was estimated to be 10 lbs.

$$Treq = 17.13 \times 68 \; / (3700 \times 0.0015) - 10 = 199.88 \text{ lb.ins}$$

To stop the starwheel, an additional torque caused by weight of the markers must be overcome.

$$Treq = W(r_p) = 35 \times 0.725 = 25.4 \text{ lb.ins}$$

Therefore the total torque sums up to 225.38 lb.ins. Referring to the manufacture chart, size CB-5 was selected. The static torque of CB-5 is 250 lb.ins.

2) Size checking

This initial selection has to be verified by adding unit inertia (rotating components) to load inertia calculated, and the size double checked by computing new data with torque formula. From technical rating data provided by manufacture, unit inertia WR2unit = 0.1950lb.in2, the corrected torque load is

$$T_{crrt} = (WR^2_{load} + WR^2_{load}) \; N/3700t - T_{fri} = 202.27 \text{ lb.ins}$$

The total torque required is therefore 227.65 lb.ins. It concludes that CB-5 is the correct size.

3) Minimum torque required

In order to fulfill the clutch/brake accuracy capability of± 1/2°, a minimum load inertia is required to fully engage the brake spring and disengage the clutch spring. This minimum inertia (I) can be calculated from accompanying formula:

$$I = (t)\,(Tc + Tf)\; 3700/N - Ic$$

Where I = minimum inertia required to fully activate the clutch/brake (lb.in2)

t = time in seconds

Tc = torque required to fully activate the clutch/brake (in.lb)

Tf = drag torque (in.lb)

Ic = inertia at the output side of the clutch (ib.in).

From manufacture data for CB-5, Tc = 6.88, t = 0.004, Ic =0.1663, the minimum inertia required is 3.51 lb.in2. Compare to the system load inertia calculated previously (17.13 lb.in2), no further action (such as increasing weight of some rotating parts) is required.

APPENDIX C - 2

Calculations in Design of Marker Delivery System

1) The length of delivery belt

In order to provide zero relative velocity to the road surface, the horizontal component of the marker velocity must equal to vehicle speed, i.e.,

$$V_x = V_{truck} = 14.7 \text{ fps}$$

Laid from a belt with slope of 30°, the velocity of the maker has to be:

$$V_{marker} = V_x / \cos 30° = 17 \text{ fps}$$

$$V_{belt} = V_{marker} = 17 \text{ fps}$$

To lay markers every four feet from a belt at linear velocity of 17 fps, the interval between cleats should be 4/cos 30°, the length of the belt with two profiles is therefor,

$$L = 4 / \cos 30° \times 2 = 110.9 \text{ ins}$$

2) Length checking

According to belt configuration, the horizontal part and inclined part are 25" and 22" respectively, i.e. (refer to Fig.3.2),

$$l_1 = 25", \ l_2 = 22" \text{ and } l_3 = 45.6"$$

where l3 was measured graphically. since the pulleys are all equal sized, the calculation of the belt length can be simplified.

$$L_{ck} = l_1 + l_2 + l_3 + 3.14Dp = l_1 + l_2 + l_3 + TP$$

$$= 25 + 22 + 45.6 + 35 \times 0.5 = 110.1"$$

where Dp is pitch diameter of the pulleys, T is the number of tooth and P is the pitch of the pulleys. The result indicated that the proportion is acceptable.

3) Mounting height of the belt frame (Fig 3.2)

$$H = h + r + l_2 \sin 30° = 2 + 3 + 22 \times 0.5 = 16"$$

where h = 2", the clearance from the belt surface to the ground,

r = 3". the radius of the pulley measured at belt surface.

APPENDIX C - 3

Size Selection of Electric Clutch/brake (from KABCO)

1) Torque required

$$T_{ave} = WR^2N/(308t)$$

where Tave is total average torque required in lb.ft, WR2 is load inertia, N is revolution speed at clutch/brake location in rpm and t is response time in second.

For pulleys, weight W = 12 lbs, Pitch diameter Dp = 5.57" = 0.464'

$$WR^2 = W(r^2/2) = W(Dp/2)^2/2 = 0.315 \text{ lb.ft}^2$$

Total inertia for three pulleys

For two gears, D = 6" = 0.5', l = 0.5",

$$WR^2 = 0.25 \times 0.5 \times 2 = 0.25 \text{ lb.ft}^2$$

For linear parts, Wbelt = 5.5 lbs, Wdot = 0.5 lbs,

$$WR^2 = W\, r^2 = 6 \times 0.464^2 = 0.315 \text{ lb.ft}^2$$

Total inertia

$$WR^2 = 0.945 + 0.25 + 0.315 = 1.51 \text{ lb.ft}^2$$

The average torque

$$T_{ave} = WR^2N/(308t) = 22.88 \text{ lb.ft}$$

where N ≐ 697 rpm, and t = 0.15 sec.

From manufacture data, size 9 was selected.

2) Heat dissipation

Heat dissipated from linear parts is calculated with the formula

$$E_{linear} = mv^2/2$$

where m is the mass of linear moving parts in lb mass, and v is the velocity in ft/sec. $E_{linear} = mv^2/2 = (6\ /32.2)(17)2/2 = 26.93$ ib.ft = 36.4 Joules

Heat dissipated from rotating parts can be calculated using the formula:

$$E_{rotat} = 1.7WR^2(n/100)2 = 1.7(0.945 + 0.25)(697/100)2 = 99.54 \text{ lb.ft}$$

$$= 134.5 \text{ Joules}$$

$$E_{total} = E_{rotat} + E_{linear} = 170.9 \text{ Joules}$$

Technical data from the manufacture show that for size 9, heat dissipation permitted is 228 J/sec for the clutch and 164 J/sec for brake. Since during braking the total dissipation will decrease due to friction, it was estimated size 9 could meet the requirement. The pulley material was late changed to aluminum to secure the C/B performance.

APPENDIX C - 4

Calculation on the drive system

Basic parameters: Wheel diameter D_{wheel} = 16"

Pulley diameter D_{pulley} = 5.57"

Sheave diameter D_{sheave} = 7.64"

Slope of the delivery belt is 30°

Ratio of wheel-delivery pulley $R_1 = D_{wheel}/(D_{pulley} \cos 30°) = 3.32$

Ratio of wheel-press pulley $R_2 = D_{wheel}/D_{pulley} = 2.873$

Ratio of wheel-sheave $R_3 = D_{wheel}/D_{sheave} = 2.11$

The prime diving sprocket was chosen $T_1 = T_6 = 76$ (refer to Fig.5.2)

$T_2 = T_1/R_1 = 76 / 3.32 = 22.89$, chose $T_2 = 23$

$T_6 = T_5/R_2 = 76 / 2.873 = 26.45$, chose $T_6 = 26$

$T_8 = T_2/R_3 = 76 / 2.11 = 36$

When the truck is at 10 mph, V_{truck} = 10 mph = 14.7 fps

the angular speed of the wheel

$N_{wheel} = 60 V_{truck} / 3.14 D_{wheel} = 212$ rpm

$N_{d\text{-}pulley} = N_{wheel} \times T_1 / T2 = 700.5$ rpm

$N_{p\text{-}pulley} = N_{wheel} \times T_1 / T6 = 619.7$ rpm

$N_{sheave} = N_{wheel} \times T_1 / T8 = 447.6$ rpm

APPENDIX D

USER'S GUIDE TO OPERATION

• Plug in all connectors at panel in front of vehicle; make sure mating connectors are correct; the two larger military style connectors are marked with stickers on their cables, one is J5, the other is J6; make sure these numbers correspond with the numbers of the cables on other side of panel also plug in the smaller military style connector; all of these described cable--connector assemblies are for data transmission.

There are three chrome plated trailer style connectors which make power connection; make sure the wire colors match on either side to the panel -- red goes red, black goes black, and the lamp cords match with lamp cord lines.

• Plug in remaining a.c.. line which feeds power to the starwheel motor.

• Plug in mating connectors to the white main circuit box; cables and box are marked; pull back plastic wire loom covering on cables and stickers that label J1- - J6.

• Turn on starwheel motor to the setting of o.8 of the full scale; the knob is located on the side of the automated vehicle near the starwheels.

• Turn on the white main circuit box

-All LED's may momentarily be on when controller is initially turned on; controller is powered up as soon as main circuit box is connected with the small cable with the chrome connector.

- If LED's remain on, the controller must be reset; turn off pain power box at switch and then momentarily unplug the chrome connector; unplugging this cable will cut power to the controller (12 vdc source); and to the remaining electronics external to the controller (5 vdc source); merely turning off the switch on the main circuit box will not reset the controller.

• Turn on the white over voltage unit.

• Turn on the relay module; the relay module must go on after the main circuit box and be turned off before the main circuit box is turned off; if the relay module id on by itself, it will continuously operate the starwheel assembly and markers will fall out of the hoppers uncontrolled.

• Assuming the belts have had a chance to line up to their respective home positions, marker application may begin.

Explanation of the Various Switches and Buttons on Main Circuit Box

- The "reflective/nonreflective" toggle switch dictates which starwheel will be activated when in single marker operation mode or when manually triggering the starwheel mechanism.

- The "pattern/single" toggle switch dictates whether the automated vehicle will operate in single marker mode of apply the marker pattern when the "start" button is depressed.

-The "start" button activates the marker application cycle; if set for "single" marker application, all mechanisms will reset and stop after the marker has been applied, if set for "pattern" application, the operation will be continuous until the "stop" button has been depressed.

- The "on" and "off" buttons for the glue and delivery belts are manual activation buttons that activate or deactivate their respective belts independent of the normal operation cycle.

- The "starwheel" button manually operates the starwheel mechanism independent of the normal operating cycle; the particular starwheel operated is dictated by the selection of the "reflective/nonreflective" switch.

- The dipswitch settings dictates where the various pertinent conveyor belt positions will be sensed' the encoder outputs are compared with these settings; the left most dipswitch of each pair is the high adjust and the tight is the low adjust; group of dipswitches labeled "comparator" is not used.

•"Shutoff/drop" dipswitch is the shutoff position of the delivery belt.

• "Shutoff" dipswitch is the shutoff position of the glue belt.

•"Starwheel" depswitch is set at delivery belt position in which cleat is just past the region where the starwheel drop the markers

- "Adder" dipswitch determines the timing of the patch of adhesive on the road surface and the placement of the marker; adjusting the switch setting to a lower hexadecimal number will "advance" the timing of the marker in relation to the adhesive patch; adjusting the switch settings to a higher hexadecimal setting will advance the adhesive patch in relation to the marker.

APPENDIX E

COMPUTER PROGRAM

APPENDIX E

COMPUTER PROGRAM

```
10      REM * MICRO-440 PROGRAM TO CONTROL RPMM SEQUENCE CONTROL
20      REM ****************************************************
30      REM
40      REM
50      REM
90      REM **MAIN BODY OF PROGRAM**
92      REM
95      REM CLEAR OUTPUT PORTS
100     PORT1=PORT1.AND.0FCH : PORT3=PORT3.AND.0CFH
105     REM MAKE SURE INTERRUPTS CAN BE READ
130     GOSUB 1500 :  REM LINE UP BELTS TO HOME POSITION
150     XBY(0FF00H)=15 : PS=XBY(0FF00H)  :  REM CONFIG. A/D CH.8
160     IF PS<0C0H THEN 2000 :  REM IF "HI" JUMP TO SINGLE DOT SECTION
163     GOSUB 1500 :  REM LINE UP BELTS TO HOME POSITION
165     XBY(0FF02H)=11 : STW=XBY(0FF02H)  :  REM MANUAL STARW TRIG-A/D CH.4
170     XBY(0FF03H)=13 : NR=XBY(0FF03H)  :  REM REFL/NONR-A/D CH.6
175     IF NR>0C0H.AND.STW>0C0H THEN  GOSUB 5030
177     IF NR<0C0H.AND.STW>0C0H THEN  GOSUB 5000
180     XBY(0FF01H)=14 : STRT=XBY(0FF01H)  :  REM CONFIGURE A/D CH.7
190     IF STRT<0C0H THEN 150 :  REM IF "HI" THEN BEGIN PATT.,LOW LOOP BACK
200     REM *****
202     REM * MAIN LOOP FOR PATTERN APPLYING MODE
203     REM *****
210     GOSUB 1500 :  REM LINE UP BELTS TO HOME POSITION
215     GOSUB 500 :  REM 4 DOTS SUBROUTINE
220     XBY(0FF04H)=12 : STP=XBY(0FF04H)  :  REM CONFIG.A/D CH.5
230     IF STP>0C0H THEN 180 :  REM IF CH.5 "HI" THEN STOP EXEC.
235     GOSUB 1500 :  REM LINE UP BELTS TO HOME POSITION
240     GOSUB 1000 :  REM 18' SECTION
245     GOSUB 1500 :  REM LINE UP BELTS TO HOME POSITION
250     XBY(0FF04H)=12 : STP=XBY(0FF04H)  :  REM CONFIG.A/D CH.5
260     IF STP>0C0H THEN 180 :  REM IF "HI" THEN STOP EXEC.
270     GOSUB 1200 :  REM LAY REFL DOT SECTION OF PROGRAM
280     XBY(0FF04H)=12 : STP=XBY(0FF04H)  :  REM CONFIG.A/D CH.5
290     IF STP>0C0H THEN 180 :  REM IF "HI" THEN STOP EXEC.
295     GOSUB 1500 :  REM LINE UP BELTS TO HOME POSITION
300     GOSUB 1000 :  REM 18' SEC
303     GOSUB 1500 :  REM LINE UP BELTS TO HOME POSITION
305     IF STP>0C0H THEN 180 :  REM IF "HI" THEN STOP EXEC.
310     XBY(0FF04H)=12 : STP=XBY(0FF04H)  :  REM CONFIG.A/D CH.5
320     IF STP>0C0H THEN 180 ELSE 210 :  REM IF "HI" THEN STOP, ELSE RE
325     REM *****
330     REM * END MAIN LOOP FOR PATTERN APPLYING MODE
335     REM *****
490     REM *****
```

```
495    REM * SUBROUTINE TO APPLY 4 NONREFLECTIVE MARKERS
497    REM *****
500    GOSUB 5000 :  REM TRIGG 1ST OF 4 DOTS
510   DELAY=0 :  GOSUB 6000 :  PRINT "START DELAY COUNT"
540   PORT1=PORT1.OR.1H :  PRINT "GLUE BELT ON"
545   GENCODER=PORT1.AND.9H
547    GOSUB 6000 :  REM UPDATE
550    IF GENCODER=9H THEN 560 ELSE 545
560   GENCODER=PORT1.AND.81H :  REM CHECK FOR TRIGGER POS
565    IF GENCODER=81H THEN 570 ELSE 560
570    GOSUB 6000
580   PORT1=PORT1.OR.2H :  PRINT "DEL BELT ON"
585    GOSUB 6000
587    REM CHECK PORT1.6 AND 1.5(A<B-STARWHEEL,A>B-SHUTOFF)
590   DENCODER=PORT1.AND.60H
600    IF DENCODER=60H THEN 610 ELSE 585 :  REM IF CLEAT PAST STARW, DROP DOT
610    GOSUB 5000 :  REM TRIGG 2ND DOT
620    GOSUB 6000
630   DENCODER=PORT1.AND.10H :  REM READ PORT1.4(A<B-SHUTOFF)
640    IF DENCODER=0 THEN 620 :  REM CHECK IF DEL BELT PAST SHUT POS
642    PRINT "END DELAY COUNT ",DELAY
644    IF DELAY>50 THEN DELAY=0
645    REM CHECK PORT1.6 AND 1.5(A<B-STARWHEEL,A>B-SHUTOFF)
650   DENCODER=PORT1.AND.60H
660    IF DENCODER=60H THEN 670 ELSE 650 :  REM IF CLEAT PAST STARW,DROP DOT
670    GOSUB 5000 :  REM TRIGG 3RD DOT
680   DENCODER=PORT1.AND.10H :  REM CHECK PORT1.4(A<B-SHUTOFF)
710    IF DENCODER=0 THEN 680 :  REM CHECK IF DEL BELT PAST SHUTOFF POS
720   DENCODER=PORT1.AND.60H
750    IF DENCODER=60H THEN 760 ELSE 720 :  REM IF CLEAT PAST STARW,DROP NEXT
760    GOSUB 5000 :  REM TRIGG 4TH DOT
790   DENCODER=PORT1.AND.10H :  REM CHECK P1.4(A<B-SHUTOFF)
800    IF DENCODER=10H THEN 810 ELSE 790
810   GENCODER=PORT1.AND.5H :  REM CHECK P1.2,1.0(A<B-SHUTOFF,GB OUTPUT)
820    IF GENCODER=5H THEN 830 ELSE 835
830   PORT1=PORT1.AND.0FEH :  PRINT "GLUE BELT OFF"
835   DENCODER=PORT1.AND.60H :  REM CHECK P1.6,1.5(A<B-STARW,A>B-SHUT)
840    IF DENCODER=60H THEN 850 ELSE 810 :  REM CHECK IF CLEAT PAST STARW
850   GENCODER=PORT1.AND.5H :  REM CHECK P1.2,1.0(A<B-SHUTOFF,GB OUTPUT)
860    IF GENCODER=5H THEN 865 ELSE 870
865   PORT1=PORT1.AND.0FEH :  PRINT "GLUE BELT OFF"
870   DENCODER=PORT1.AND.10H :  REM CHECK P1.4(A<B-SHUTOFF)
880    IF DENCODER=10H THEN 890 ELSE 870
890   PORT1=PORT1.AND.0FDH :  PRINT "DEL BELT OFF"
892   GDB=PORT1.AND.3H :  IF GDB<>0 THEN  GOSUB 1500 ELSE  RETURN
895    RETURN  :  REM END SECTION TO LAY 4 DOTS
896    REM *****
897    REM * END SUBROUTINE TO APPLY 4 NONREFLECTIVE MARKERS
898    REM *****
899    REM
900    REM *****
910    REM * SUBROUTINE TO SPACE 18 FEET OF ROAD SURFACE
920    REM *****
1000  INC=0 : S=0 : VALUE=79 :  REM INITIALIZE VALUES,79 PULSES/18'
1020   GOSUB 1070
1030  XBY(0FF04H)=12 : STP=XBY(0FF04H) :  REM CONFIG A/D CH.5
1040   IF STP>0C0H THEN  RETURN
1045  S=INC
1050   IF S>VALUE THEN  RETURN  ELSE 1020
1060   REM READ INC. ENCODER
1070  B=PORT3.AND.8H :  IF B=8H THEN 1080 ELSE  RETURN
1080  INC=INC+1 :  PRINT "COUNT ",INC :  RETURN  :  REM END 18' SECTION
1085   REM *****
```

```
1090   REM * END SUBROUTINE TO SPACE 18 FEET OF ROAD SURFACE
1095   REM *****
1097   REM
1099   REM *****
1190   REM *SUBROUTINE TO APPLY REFLECTIVE MARKER
1195   REM *****
1200  X=0 :  GOSUB 5030 :  REM TRIGGER REFL. STARW
1205   IF X=0 THEN 1200 :  REM CHECK IF REFL. DOT HAS PAST
1210   GOSUB 1330 :  REM RUN BELTS FOR SINGLE CYCLE
1220   RETURN
1225   REM *****
1227   REM * END SUBROUTINE TO APPLY REFLECTIVE MARKER
1229   REM *****
1300   REM
1310   REM *****
1315   REM * SUBROUTINE TO RUN BELTS FOR SINGLE MARKER CYCLE
1317   REM *****
1330  DELAY=0 :  PRINT "BEGIN DELAY COUNT"
1340   GOSUB 6000
1350  PORT1=PORT1.OR.1H :  PRINT "GLUE BELT ON"
1355  GENCODER=PORT1.AND.9H :  GOSUB 6000
1357   REM CHECK IF GLUE BELT IS PAST ZERO POSITION YET
1360   IF GENCODER=9H THEN 1365 ELSE 1355
1365  GENCODER=PORT1.AND.81H :  GOSUB 6000
1367   REM CHECK FOR TRIGG POSITION
1370   IF GENCODER=81H THEN 1380 ELSE 1365
1380   GOSUB 6000
1390  PORT1=PORT1.OR.2H :  PRINT "DEL BELT ON"
1391   REM CHECK IF DEL BELT IS ON
1392  DENCODER=PORT1.AND.2H :  IF DENCODER=0 THEN 1390
1400  GENCODER=PORT1.AND.5H :  REM CHECK P1.2,1.0(A<B-SHUTOFF,GB OUTPUT)
1405   GOSUB 6000
1410   IF GENCODER=5H THEN 1415 ELSE 1400
1415  PORT1=PORT1.AND.0FEH :  PRINT "GLUE BELT OFF"
1420  DENCODER=PORT1.AND.10H :  REM CHECK P1.4(A<B-SHUTOFF)
1425   GOSUB 6000
1430   IF DENCODER=10H THEN 1435 ELSE 1420
1435  PORT1=PORT1.AND.0FDH :  PRINT "DEL BELT OFF"
1440  DGB=PORT1.AND.3H
1445   IF DELAY>50 THEN DELAY=0
1450   IF DGB<>0 THEN  GOSUB 1500 ELSE  RETURN
1455   RETURN
1457   REM *****
1460   REM * END SECTION TO RUN BELTS FOR SINGLE MARKER CYCLE
1465   REM *****
1467   REM
1468   REM *****
1470   REM * SUBROUTINE TO LINE UP BELTS TO HOME POSITION
1475   REM *****
1500  GB=PORT1.AND.1H : DB=PORT1.AND.2H :  REM CHECK P1.0,1.1
1510  GENCODER=PORT1.AND.4H :  REM CHECK P1.2(A<B-SHUTOFF)
1520  DENCODER=PORT1.AND.10H :  REM CHECK P1.4(A<B-SHUTOFF)
1530   IF GENCODER=0.AND.GB=0 THEN PORT1=PORT1.OR.1H :  PRINT "GLUE BELT ON"
1540   IF DENCODER=0.AND.DB=0 THEN PORT1=PORT1.OR.2H :  PRINT "DEL BELT ON"
1550   IF GENCODER>0.AND.GB>0 THEN PORT1=PORT1.AND.0FEH :  PRINT "GLUE BELT OFF"
1560   IF DENCODER>0.AND.DB>0 THEN PORT1=PORT1.AND.0FDH :  PRINT "DEL BELT OFF"
1565  GB=PORT1.AND.1H : DB=PORT1.AND.2H :  REM CHECK P1.0.1.1
1570   IF GB=0.AND.DB=0 THEN  RETURN  ELSE 1500
1575   RETURN
1577   REM *****
1580   REM * END OF SUBROUTINE TO LINE UP BELTS TO HOME POSITION
1585   REM *****
1590   REM
```

```
1600   REM *****
1990   REM * SECTION FOR SINGLE MARKER MODE
1995   REM *****
2000  XBY(0FF01H)=14 : STRT=XBY(0FF01H)  :  REM CONFIG A/D CH.7
2010  XBY(0FF03H)=13 : NR=XBY(0FF03H)  :  REM CONFIG A/D CH.6
2020  XBY(0FF00H)=15 : PS=XBY(0FF00H)  :  REM CONFIG A/D CH.8
2030   IF NR>0C0H.AND.STRT>0C0H THEN 2040 ELSE 2060 :  REM START,REFL DOT
2040   GOSUB 5030 :  REM TRIGG REFL DOT
2050   GOSUB 1330 :  REM RUN BELTS FOR SINGLE CYCLE
2060   IF NR<0C0H.AND.STRT>0C0H THEN 2070 ELSE 3000 :  REM START,NONR DOT
2070   GOSUB 5000 :  REM TRIGG NONR DOT
2080   GOSUB 1330 :  REM RUN BELTS FOR SINGLE CYCLE
3000  XBY(0FF08H)=11 : STW=XBY(0FF08H)  :  REM CONFIG. A/D CH.4
3020   IF NR>0C0H.AND.STW>0C0H THEN  GOSUB 5030 :  REM MANUAL STW TRIGG,REFL
3030   IF NR<0C0H.AND.STW>0C0H THEN  GOSUB 5000 :  REM MANUAL STW TRIGG,NONR
3035   GOSUB 1500 :  REM LINE UP BELTS TO HOME POSITION
3040   IF PS>0C0H THEN 150 ELSE 2000
3045   GOTO 2000
3047   REM *****
3050   REM * END SECTION FOR SINGLE MARKER MODE
3060   REM *****
3080   REM
3090   REM *****
4990   REM * SUBROUTINE TO TRIGGER NONREFLECTIVE STARWHEEL RELAY
4995   REM *****
5000  TIME=0 :  CLOCK 1 :  DO
5010  PORT3=PORT3.OR.10H
5020   WHILE TIME<.08 : PORT3=PORT3.AND.0EFH
5022   PRINT "NONR DOT"
5023   IF STW>0C0H THEN 5024 ELSE  RETURN
5024   FOR J=1 TO 500 :  NEXT J :  RETURN
5025   REM *****
5026   REM * END SUBROUTINE TO TRIGGER NONREFLECTIVE STARWHEEL RELAY
5027   REM *****
5028   REM
5029   REM *****
5030   REM * SUBROUTINE TO TRIGGER REFLECTIVE STARWHEEL RELAY
5031   REM *****
5035  TIME=0 :  CLOCK 1 :  DO
5040  PORT3=PORT3.OR.20H
5050   WHILE TIME<.1 : PORT3=PORT3.AND.0DFH
5051  X=1
5052   PRINT "REFL DOT"
5053   IF STW>0C0H THEN 5055 ELSE  RETURN
5055   FOR J=1 TO 500 :  NEXT J :  RETURN
5056   REM *****
5057   REM * END SUBROUTINE TO TRIGGER REFLECTIVE STARWHEEL RELAY
5058   REM *****
6000   RETURN

READY
>CLOE
```

CB-5 Specifications

Designed expressly for the industrial and business machine market, this CB unit is suitable for indexing and rapid cycling in heavy-duty machinery such as crimpers, check cancellers, packaging equipment, etc.

Technical Ratings

Static Torque	250 lb. in.
Maximum anti-overrun holding capability	45 lb. in.
Maximum anti-back holding capability	160 lb. in.
Inertia, rotating parts	.1950 lb. in.^{2}
Maximum radial bearing load at maximum speed	32 lb.
Maximum operating speed	750 RPM
Response time, voltage on at full speed	27 MS

See page 44 for minimum inertia requirements.
See page 45 for mounting instructions.

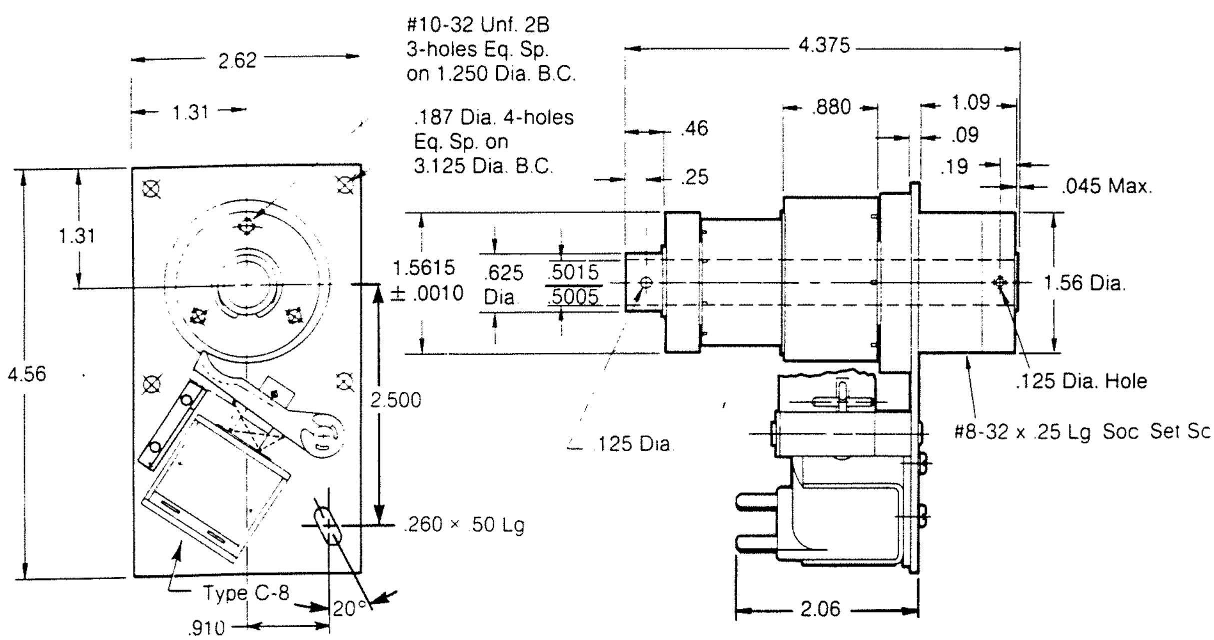
Electrical Characteristics

(Coils are rated for continuous duty)

Voltage	Current (Amps)	Resistance (Ohms)
115 AC 60 Hz	*.103	280
24 DC	.325	74
12 DC	.732	16.4
90 DC	.096	936

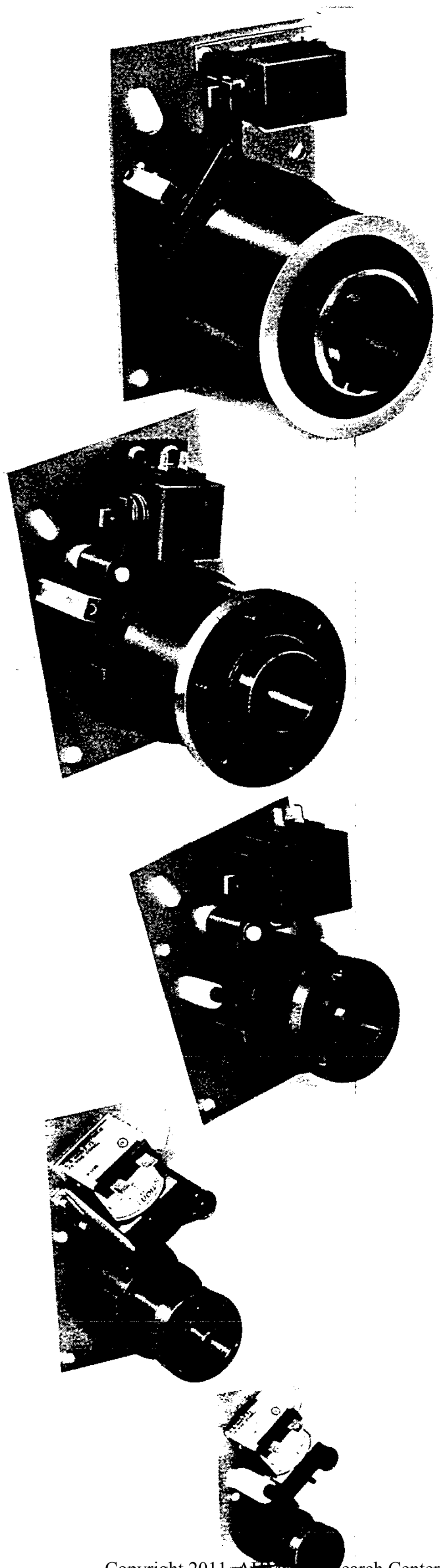
*115 AC—In rush current—.232 Amps
Holding current—.098 Amps

Dimensions



How to Order For Ordering Information and Modifications, See Page 19.

Standard CB Series Selection

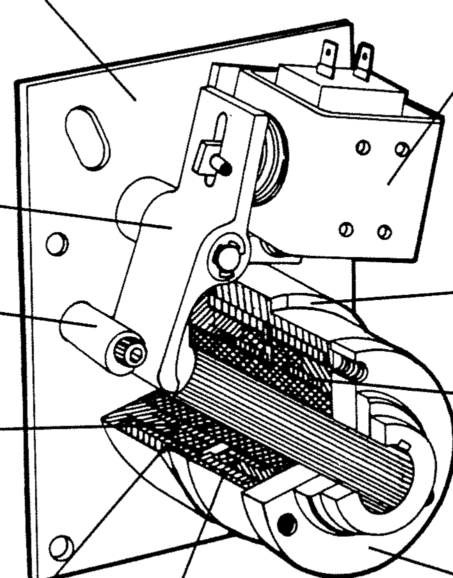


CB series combination clutches and brakes accurately start and stop loads driven by a continuously rotating power source. CB units operate from a single AC or DC pulse, stopping the load within ±½° noncumulative at speeds up to 1800 RPM. Each unit is pre-engineered and pre-assembled for easy installation.

- Adjustable control collars for easy and accurate output stop position setting
- Load over-travel or back-up is eliminated since CB units lock the load in both directions when the solenoid is off
- Actuator limit stop for solenoid protection is standard on all models
- Anti-overrun feature prevents the output from running faster than the input
- Permanently lubricated, never need adjustment for wear
- Bring loads up to speed in 3 milliseconds and stop within 1.5 milliseconds
- Easy interface to PC's and other controls including Warner Electric Photoscanner photoelectrics
- Single stop collar standard, 2 and 4 stop collars optional. Multi-stop collars with up to 24 stops available as specials
- AC or DC operated—other voltages available
- See pages 40 and 41 for controls and power supplies.

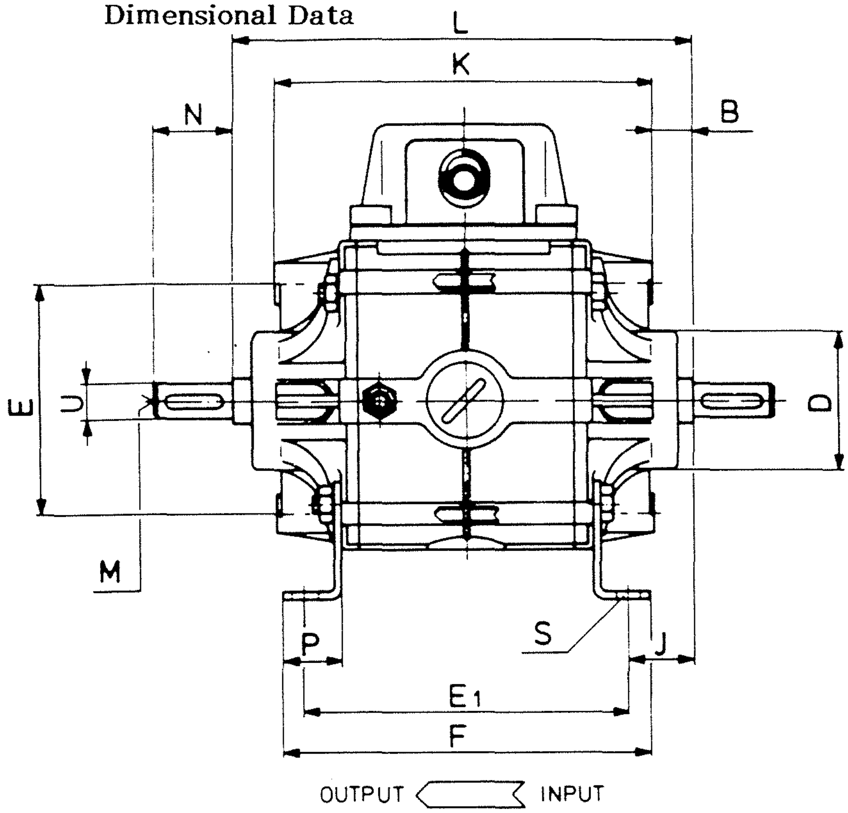
Selection

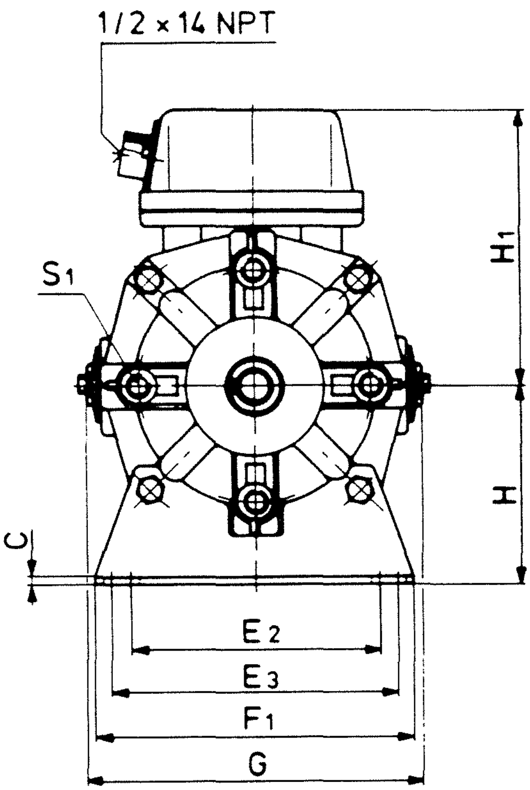
Model	Static Torque lb. ins.	RPM Max.	Shaft Diameter: Standard	Shaft Diameter: Special Order	Page
CB-2	25	1800	¼″		20-21
CB-4	120	1200	⅜″		22-23
CB-5	250	750	½″		24-25
CB-6	500	500	¾″ or 1″		26-27
CB-8	2500	300	1¼″ or 1½″	1″ or 1⅜″	28-29
CB-10	5000	200	1½″	1⅝″ or 1¾″	30-31



CLUTCH-BRAKE COMBINATIONS / KEBCO-COMBIBOX

Dimensional Data





ELECTRIC CLUTCH/ELECTRIC BRAKE - TYPE 10 AND
HOUSED ELECTRIC CLUTCH ONLY - TYPE 09

MODEL 10.360 (WITHOUT FEET) ; MODEL 10.370 (WITH FEET)

SIZE	TORQUE lb.ft.	WATTS CLUTCH	WATTS BRAKE	B	C	D	E	E_1	E_2	E_3	F	F_1	G	H	H_1	J	K	L	M	P	S	S_1	WEIGHT LBS.
06	5	15	12	.514	.11	1.732 1.731	2.83	3.94	3.15	3.35	4.53	3.94	4.06	2.48	3.43	.84	4.60	5.63	M 4	.71	.275	M 6	5.7
07	11	20	16	.514	.12	1.969 1.967	3.54	4.53	4.13	4.33	5.43	5.12	4.92	2.80	3.70	1.01	5.52	6.54	M 5	.98	.354	M 8	7:7
08	22	28	21	.594	.16	2.441 2.439	4.41	5.31	5.12	5.51	6.30	6.30	6.22	3.54	4.25	1.33	6.77	7.96	M 8	1.10	.354	M 8	16.5
09	48	35	28	.707	.20	2.913 2.912	5.39	6.10	5.91	6.30	7.09	7.09	7.28	3.94	5.08	1.51	7.72	9.13	M10	1.18	.430	M10	28.6
10	96	50	38	.866	.24	3.740 3.738	6.89	7.28	7.28	7.68	8.46	8.78	9.30	5.20	6.06	2.15	9.84	11.57	M12	1.50	.510	M12	55.0

SIZE	INPUT U	INPUT N	OUTPUT U	OUTPUT N	KEY
06	.5000 .4995	1.50	.5000 .4995	1.50	1/8 x 1/8
07	.6250 .6245	1.90	.6250 .6245	1.90	3/16x3/16
08	.8750 .8745	2.00	.8750 .8745	2.00	3/16x3/16
09	1.1250 1.1245	2.75	1.1250 1.1245	2.75	1/4 x 1/4
10	1.3750 1.3744	3.50	1.3750 1.3744	3.50	5/16x5/16

ALL DIMENSIONS GIVEN IN INCHES

NOTE:
Larger sizes (185 lb.ft., 370 lb.ft.) and other NEMA-adaptions are available.
Standard coil voltages are 6, 12, 24, 48, or 95 volts DC. Other voltages available on request.

Switching Time

ELECTRIC CLUTCH/ELECTRIC BRAKE - TYPE 10 AND
HOUSED ELECTRIC CLUTCH ONLY - TYPE 09

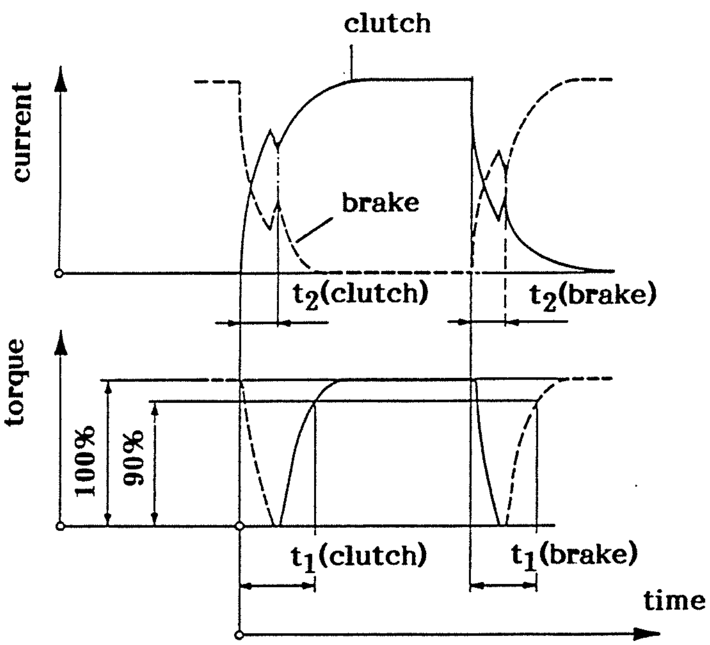
	Engagement Time t_1		Delay Time t_2		With Voltage Boost (3x nominal voltage)			
Size	Clutch	Brake	Clutch	Brake	t_1 (clutch)	t_1 (brake)	t_2 (clutch)	t_2 (brake)
06	50	45	18	18	18	18	8	10
07	90	50	28	20	40	25	10	15
08	100	70	38	25	45	30	15	20
→ 09	200	150	45	50	80	70	25	30 ←
10	250	180	75	55	120	80	35	40
11	280	210	90	65	160	110	45	50

All values given in milliseconds

ELECTRIC CLUTCH/ELECTRIC BRAKE
COMBIBOX TYPE 10, TYPE 09

3a @ 12V
V/I = R = 4Ω
36V for 30ms

Switching Time



Note:

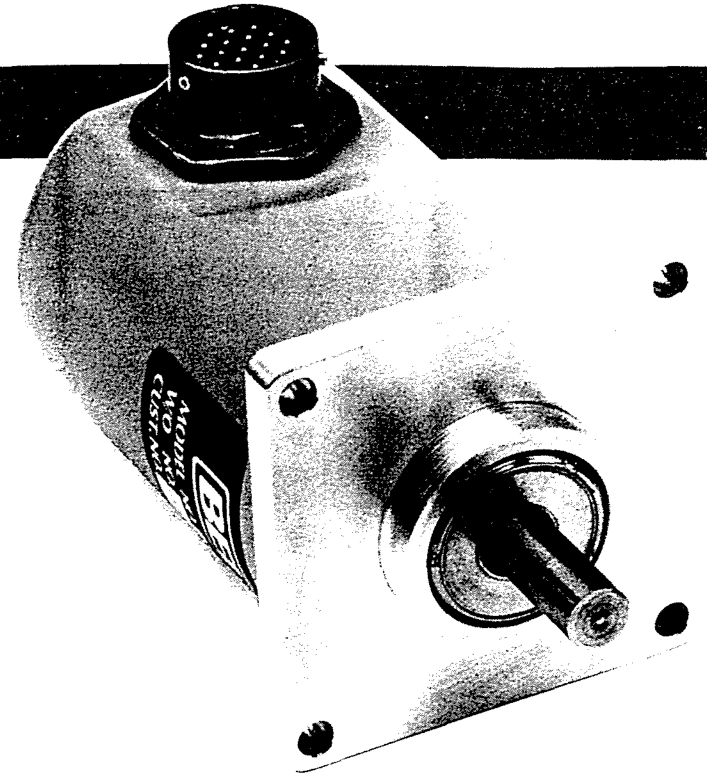
t_2 (clutch) = Delay time - time required, before the armature makes contact with the friction lining of the clutch.

t_2 (brake) = Delay time - time required, before the armature makes contact with the friction lining of the brake.

t_1 (clutch) = Engagement time - time needed until clutch has 90% nominal torque.

t_1 (brake) = Engagement time - time needed until brake has 90% nominal torque.

K25



Absolute Position Encoder

We have combined precision tooling techniques and design in optical technology to provide you with a more reliable and lower cost absolute optical encoder. We call it the BEI K25 shaft encoder.

The K25 is available with 360 degree BCD output and driver. You can be assured of proper tracking of position, even over large temperature variations because of a single LED source and tracking photodetector array. The K25 durable bearings and sealing options help endure rugged environments. The K25 can qualify for NEMA 12 and 13 ratings.

Single LED Source

The optics assembly utilizes a single LED source. This source has an expected operating life of more than seven years. A durable mechanical configuration is utilized to provide excellent shock resistance. The source provides the longevity and durability an industrial encoder needs.

Photodetector Array

Superior detector response speeds enable this encoder to depict accurately, fast motions as well as slow. A single substrate temperature tracking photodetector array provides the pickup of the optical signals. This silicon device gives consistent performance through demanding environmental conditions.

Precision Optics Assembly

A custom single LED source along with a precision optical system produces a uniform plane of light. This plane passes through the BEI code disc well known for accuracies. This enables the encoder to read positional accuracies far greater than most competitive units.

Reference Signal

It may get hot or cold but this encoder will keep giving you the right position information. A reference signal is used in the optics assembly to detect and adjust the optical signal level. This automatic gain control function compensates for dramatic environmental temperature changes.

Applications

The K25 will provide position feedback in: NC Machine Tools, Printing Devices, Antennas and Telescopes, Production and Process Machinery, Indexing Tables, Machining Centers, Material Handling Systems, Rolling Mills and others.

Consult the factory regarding custom features.

BEI MOTION SYSTEMS COMPANY
Chatsworth Encoder Division
9223 Deering • Chatsworth, CA 91311 • Tel: (818) 341-6161 • Fax (8[illegible]

Specifications

Mechanical

Size: See Options P and Q

Weight: 20 oz. max.

Moment of Inertia: 8.2×10^{-4} oz. in sec.^{2}

Shaft Loading: 35 lbs. radial; 30 lbs. axial

Angular Acceleration: 5×10^5 radians/sec.^{2} max.

Slewing Speed: 5000 RPM max.

Starting Torque: Standard Model 1.0 oz. in. max. With Optional Shaft Seal 2.0 oz. in. max.

Electrical

Resolution: Up to 1024, see order information

Code Format: Gray Code, Natural Binary, and Binary Coded Decimal (BCD)

Power: 5VDC ± 5%, 750 mA max for BCD
300 mA max for Gray & Binary

Output: TTL
Positive Logic
Logic 1 = 3.5 to 5 VDC, 470Ω source impedance
Logic O = .5VDC max, 3 mA sink current
Open Collector optional

Source: Single Solid State LED
Expected Life = 7 years

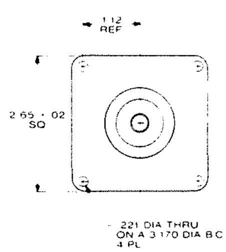
Environmental

Temperature: Operating 0°C to +70°C
Storage −65°C to +150°C

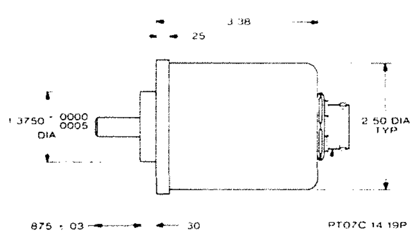
Vibration: 5 to 2000HZ at 20 G's using MIL-STD-810C method 514.2, procedure 1, figure 514.2-5, curves, table 514.2-11

Shock: 50 G's for 11 M sec duration using MIL-STD-810C method 516.2, procedure 1, figures 516.2-2

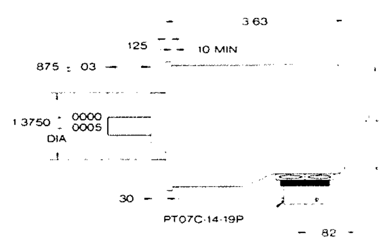
MOUNTING OPTIONS



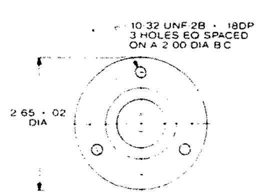
Option P



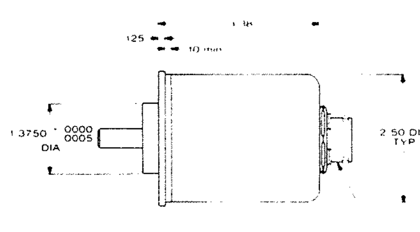
End Exit Connector



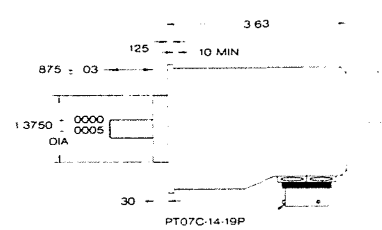
Side Exit Connector



Option Q

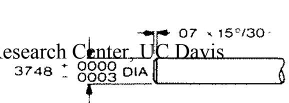


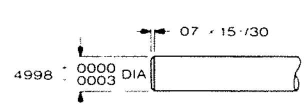
End Exit Connector



Side Exit Connector

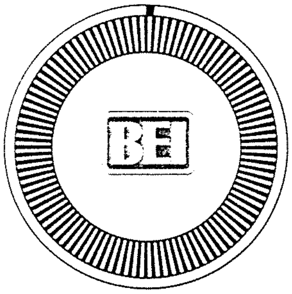
SHAFT OPTIONS





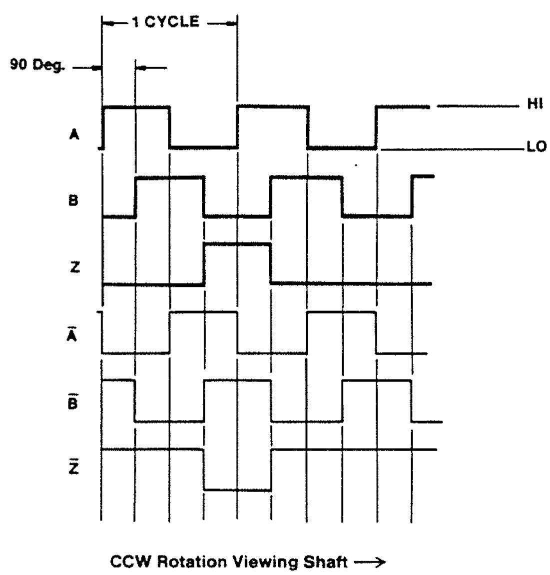
MODEL L25

INCREMENTAL OPTICAL



The L25 is a lighter duty version of BEI's H25 optical encoder. Incorporating the same high quality optics and electronics as the H25, the L25 also offers low starting torque. Other features include ABEC 7 bearings, EMI shielding, a 1/4" stainless steel shaft and a drawn aluminum cover. Typical applications include use with light machine tools, test and laboratory instrumentation, the biomedical industry and flow metering.

FIGURE 1
OUTPUT WAVEFORMS



ORDERING INFORMATION

The factory will be pleased to assist you in construction of the model number. Call toll free: 800-350-ASAP (2727)

Use the diagram below, working from left to right, to construct your model number. Notes and tables are on pages 18 and 19.

L 25 G - ☐ - ☐ - ☐ - ☐ ☐ - ☐ - ☐ - ☐ ☐ - ☐

TYPE: L = Light Duty

BASIC SIZE: 25 = 2.500

HOUSING CONFIG. LETTER: G = 2.62 Dia. Servo Mount *See Dimensions*

OPTIONAL FACE MOUNTS F1, F2, F3, or F4 Blank = None

SHAFT SEAL CONFIGURATION: SB = Seal Integral with Bearing Blank = Shielded Bearing *See Note 2*

CYCLES PER TURN: (Enter Cycles) *See Table 4*

NO. OF CHANNELS
A = Single Channel
AB = Dual Quadrature Ch.
ABZ = Dual with Index
AZ = Single with Index
See Note 3

COMPLEMENTS C = Complementary Outputs Blank = None *See Note 4*

OUTPUT I.C.: *7406, 8830, etc.* Followed by "R" = Pull-up Resistor *See Note 7*

ILLUMINATION: LED = Light Emitting Diode (Standard) Blank = Incandescent (Optional)

OUTPUT TERMINATION LOCATION: E = End S = Side

OUTPUT TERMINATION:
M16 = MS3102R16S-1P
M18 = MS3102R18-1P
D15 = DA15P
C = Pigtail Cable followed by length (i.e., C18 = Pigtail Cable 18" Long)
See Tbl. 1 & Note 11

S = Special Non-Standard Features specified on purchase order or customer's spec

Sample Model Number: The number shown below describes a common configuration of the Model L25 Encoder.

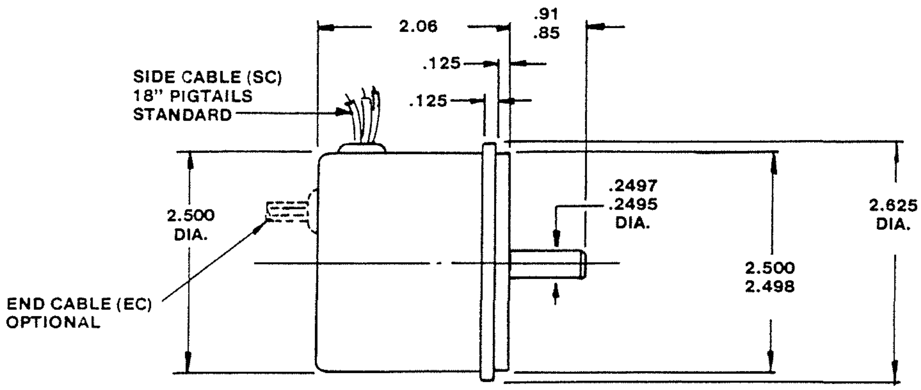
L25G-F1-SB-1000-ABZC-8830-LED-SC18

SPECIFICATIONS

DIMENSIONS

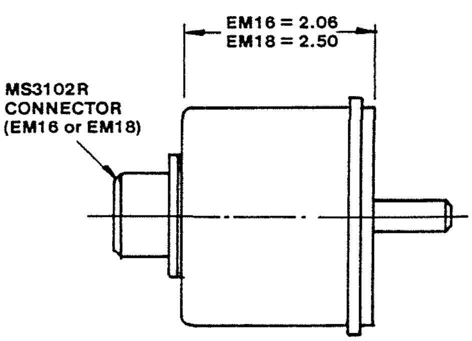
TOLERANCES:
.XX = ±.01
.XXX = ±.005

L25 G - SC18 OR EC18

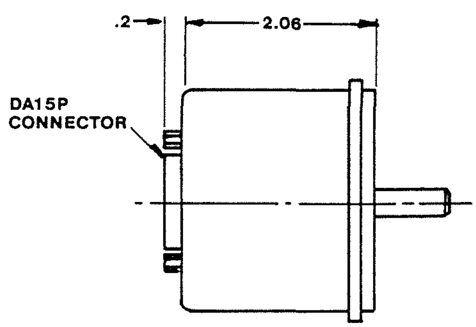


L25 G - EM16 OR EM18

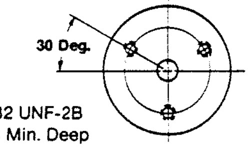
DEPENDING ON NUMBER OF OUTPUTS *(See Table 1)*



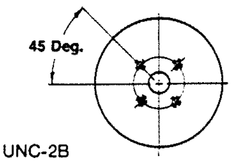
L25 G - ED15



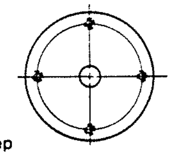
OPTIONAL FACE MOUNTS



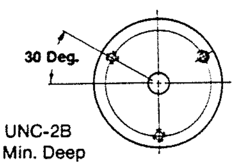
F1
10-32 UNF-2B
.188 Min. Deep
3 places equally spaced on a 1.875 Dia. bolt circle.



F2
4-40 UNC-2B
4 places equally spaced on a 1.272 Dia. bolt circle
(.900 square, Ref).



F3
4-40 UNC-2B
.250 Min. Deep
4 places equally spaced on a 2.000 Dia. bolt circle.



F4
6-32 UNC-2B
.250 Min. Deep
3 places equally spaced on a 2.000 Dia. bolt circle.

MECHANICAL

Shaft Diameter: .2497/.2495 in. diameter standard
Optional Flat on Shaft: .80 long x .03 deep
Shaft Loading: up to 5 lbs. axial and 8 lbs. radial
Shaft Runout: .0005 T.I.R. maximum
Starting Torque at 25°C (standard, without sealed bearings):
0.07 in-oz typical, 0.12 in-oz maximum
Starting Torque at 25°C (with optional sealed bearings):
0.50 in-oz typical, 1.0 in-oz maximum
Bearings: Class ABEC 7
Shaft: 416 stainless steel
Housing: die cast aluminum
Cover: drawn aluminum, .060" wall
Bearing Life: 1 x 10^9 revs. at rated shaft loading (mfr's specifications)
Moment of Inertia: 4.1 x 10^{-4} oz-in-sec^2
Weight: 13 oz. typical

NOTES AND TABLES

All notes and tables referred to in the text can be found on pages 18 and 19.

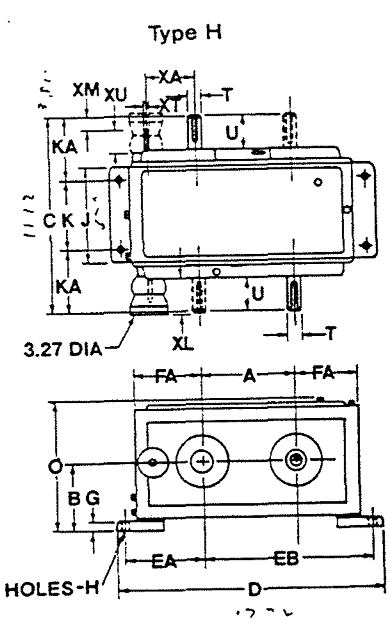
ELECTRICAL

Code: incremental
Cycles Per Shaft Turn: 1 to 2540 on code disc *(see table 4)*
Supply Voltage: +5Vdc ±5% standard, optional higher voltages available *(see note 5)*
Current Requirements:
TTL: 200 mA maximum, 150 mA typical
CMOS: 150 mA maximum, 125 mA typical
Output Format: 2 channels (A & B) in quadrature ±27° electrical *(see figure 1)*
Output Format Options: index and complementary outputs are available *(see figure 1)*
Output IC's: *(see note 7)*
Illumination: LED standard; optional incandescent lamp
Frequency Response (A & B and Index): 100 kHz *(see note 9)*
Output Terminations: *(see table 1)*
NOTE: other electrical options available *(see pgs. 14-17)*

ENVIRONMENTAL

Temperature: *operating,* 0 to 70°C standard;
optional extended temperatures *(see note 10)*
storage, −25 to 90°C
Shock: 50 G's for 11 msec duration
Vibration: 5 to 2000 Hz @ 20 G's
Humidity: 98% RH without condensation

Horizontal transmissions
50-300 series



Dimensions Type H

Drive size	Wt. lbs.	A	B	C	D	EA	EB	FA	G	H	J
		Inches									
~~050~~	~~65~~	~~5.500~~	~~4.000~~	~~11.12~~	~~17.72~~	[illegible]	[illegible]	[illegible]	~~.79~~	~~.53~~	[illegible]
100	90	6.500	4.500	12.88	19.49	5.75	12.25	5.09	.87	.53	5.98
200	180	7.500	5.500	15.62	22.24	6.50	14.00	5.74	.94	.66	7.48
300	300	9.000	6.500	19.38	26.95	7.88	16.88	6.95	1.22	.81	9.06

Drive size	K	KA	O	T▲	U	Keyseat	XA	XL	XM	XT	XU
	Inches										
~~050~~	[illegible]	~~3.81~~	~~8.47~~	~~.7500~~	~~1.88~~	~~.19 x .09 x 1.62~~	[illegible]	~~2.79~~	~~.06~~	~~.44~~	~~1.88~~
100	4.50	4.19	9.41	.9375	2.25	.25 x .12 x 2.00	3.62	2.79	.44	.44	1.88
200	5.50	5.06	11.00	1.1250	2.69	.25 x .12 x 2.50	4.12	2.75	.90	.44	1.88
300	7.00	6.19	12.81	1.3125	3.50	.31 x .16 x 3.25	5.12	2.75	1.72	.44	1.88

Have dimensions certified for installation purposes.
▲Tolerance = +.0000" −.0005"

OPERATING INSTRUCTIONS & PARTS MANUAL

PARALLEL SHAFT DC GEARMOTORS

MODELS 4Z131A THRU 4Z134A, 6A193 & 6A194

Dayton MAXI-TORQ™ PREMIUM

FORM 5S1482
02160
0290/020/1M

READ CAREFULLY BEFORE ATTEMPTING TO ASSEMBLE, INSTALL, OPERATE OR MAINTAIN THE PRODUCT DESCRIBED. PROTECT YOURSELF AND OTHERS BY OBSERVING ALL SAFETY INFORMATION. FAILURE TO COMPLY WITH INSTRUCTIONS COULD RESULT IN PERSONAL INJURY AND/OR PROPERTY DAMAGE! RETAIN INSTRUCTIONS FOR FUTURE REFERENCE.

Description

Dayton Maxi-Torq parallel shaft gearmotors contain input motors that have 90 VDC armatures, permanent magnet fields, ball bearings and externally replaceable brushes. Oil filled gearhead housing is constructed of high strength aluminum die cast alloy. Housing and cover are doweled and precision bored for accurate gear alignment. Gearing consists of helical high speed input stage for smooth operation. Other stages consist of high strength steel spur gears providing maximum load carrying capacity. All gears and pinions are heat treated for maximum durability under rated torque. Anti-friction needle bearings of high load carrying capacity are used at all positions for efficiency and dependability. The gearmotor can be mounted in any position.

WARNING: DO NOT INSTALL OR OPERATE THESE GEARMOTORS IN AN EXPLOSIVE ATMOSPHERE.

These gearmotors operate on 0 to 90 volts DC rectified power with form factor not exceeding 1.3 or on 0 to 115 volts DC non-pulsating power. Operation with power supplies providing a form factor above 1.3 may require motor derating. Gearmotor speed increases as applied voltage increases.

Specifications and Performance

MODEL	F/L* OUTPUT RPM	F/L* OUTPUT TORQUE (IN-LBS)•	INPUT MOTOR HP	MOTOR ENCLOSURE	GEAR RATIO (IN:OUT)	F/L* AMPS @90V	OUTPUT SHAFT OVERHUNG LOAD (LBS)•	APPROX. WT. (LBS)
4Z131A	109	27	1/20	TENV	16.5:1	0.6	150	12
4Z132A	51	55	1/20	TENV	35:1	0.6	150	12
4Z133A	34	82	1/20	TENV	53:1	0.6	150	12
4Z134A	18	159	1/20	TENV	101:1	0.6	150	12
6A194	9	250	1/20	TENV	208:1	0.6	150	12
6A193	5	227	1/20	TENV	336:1	0.4	150	12

(*) F/L = Full Load TENV = Totally Enclosed Non-Ventilated (•) See Installation section, page 3, for additional information; HP and Torque ratings only apply when gearmotors are driven by Dayton Models 5X412 and 6X165 or other 90VDC filtered full-wave rectified controllers with 1.3 or lower form factor, or when operating on non-pulsating 0 to 115 VDC power.

F/L Amps = average current, as measured by a DC ammeter

ADDITIONAL SPECIFICATIONS

NOTE: These specifications apply to all models in the series.
Insulation: Class B Service Factor: 1.0 Duty: Continuous; 40°C max. ambient Gearhead Oil Capacity: 7.0 ounces

Dimensions

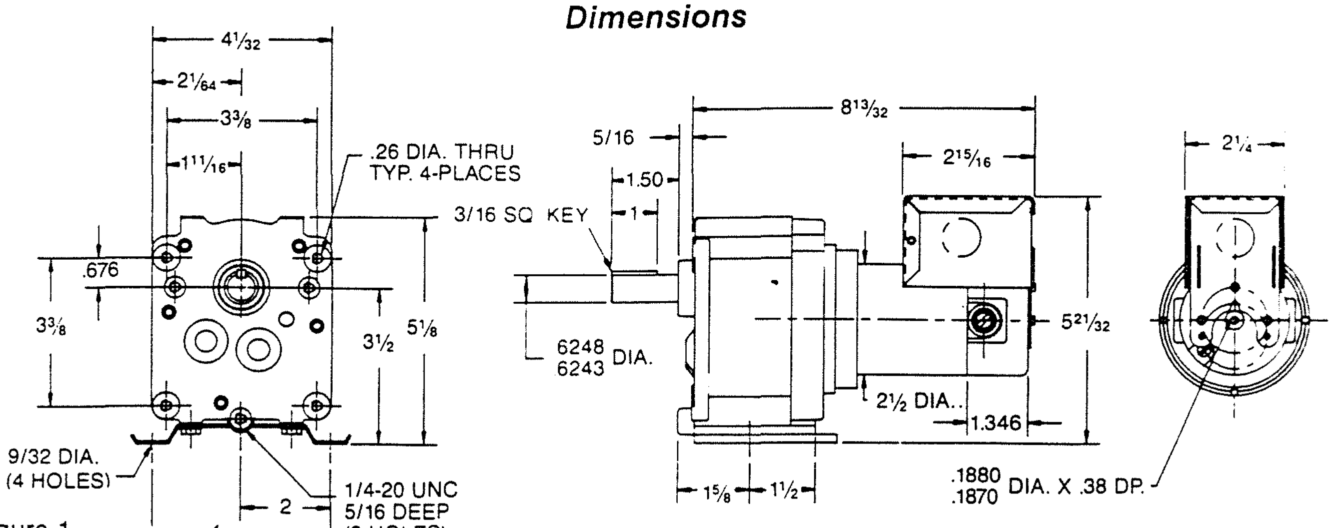


Figure 1

BRONZE AND CAST-IRON ROTARY GEAR PUMP HEADS

PUMPS: GEAR

BRONZE PUMP HEADS

Description: Bronze rotary gear pumps for recirculating, pressure boosting, filtering, spraying, or general transfer in medium to high-pressure applications. Limited self-priming capability with gears wetted. Temperature range: −40 to 210°F. Maximum pressure: 100 PSI. For use with nonflammable liquids compatible with pump component materials.

Construction: Two-piece bronze body and cover with precision-machined spur gears. Available in three variations: bronze bearings; carbon graphite bearings; and carbon graphite bearings with adjustable relief valves. Bronze bearing models (intermittent duty only) have Zerk-type grease fittings requiring periodic lubrication. Carbon graphite bearings are self-lubricating. Adjustable relief valve models are designed for occasional pressure relief of up to 1 minute. If blockage can be expected longer than one minute or on a regular basis, an external relief valve is required.

Wetted parts: Bronze gears, 303 stainless steel shafts, carbon bearings (depending on model), Kevlar packing.

Power: Not included. Pump heads can be directly coupled to a motor or power takeoff or belt driven; use of ball bearing pillow block recommended if pump is belt driven.

CAST-IRON PUMP HEADS

Description: Pedestal mount rotary gear pumps for fluid transfer, recirculation, lubrication, and chemical handling of nonabrasive, nonflammable liquids compatible with pump component materials. Limited self-priming capability. 1725 RPM maximum speed. Maximum flow, 24 GPM. Maximum pressure, 100 PSI. Nos. 1P825 through 1P830 can be operated from −40 to 225°F. Nos. 2P295 through 2P299 from −40 to 350°F. Teel brand.

Not recommended for intermittent water pumping service. A suitable relief valve must be installed if there is any restriction or closing of the discharge while the pump is operating. See ... under "Relief Valves."

Construction and wetted parts: All cast-iron body, 303 stainless steel shafts, carbon steel gears. Nos. 1P825 through 1P830 have Buna N lip seal. Nos. 2P295 through 2P299 have Kevlar packing and Zerk fittings for grease lubrication.

Power: Not included. Pumps can be belt driven or direct-

PUMP PERFORMANCE

PUMP PERFORMANCE AND MOTOR HP REQUIRED FOR WATER @ 60 TO 90°F.

Pipe Size	Pump RPM*	Free Flow GPM	Free Flow HP	20 PSI GPM	20 PSI HP	40 PSI GPM	40 PSI HP	60 PSI GPM	60 PSI HP	80 PSI GPM	80 PSI HP	100 GPM
1/8"	900	1.2	1/6	1.0	1/6	0.8	1/6	0.4	1/4	0.2	1/4	—
	1200	1.6	1/6	1.3	1/6	1.1	1/4	0.9	1/4	0.6	1/3	0.3
	1725	2.2	1/6	2.0	1/4	1.8	1/4	1.5	1/3	1.3	1/3	1.0
1/4"	900	2.2	1/6	1.8	1/6	1.5	1/4	1.2	1/4	1.0	1/3	0.8
	1200	2.9	1/6	2.5	1/4	2.2	1/3	2.0	1/3	1.8	1/2	1.6
	1725	3.8	1/4	3.7	1/3	3.5	1/2	3.2	1/2	3.0	3/4	2.8
3/8"	900	4.1	1/6	3.6	1/4	3.2	1/3	2.8	1/2	2.4	1/2	2.1
	1200	5.5	1/6	5.0	1/3	4.7	1/3	4.3	1/2	3.9	3/4	3.5
	1725	7.0	1/3	6.9	1/2	6.9	3/4	6.8	1	6.8	1 1/2	6.6
1/2"	900	5.4	1/4	4.9	1/4	4.4	1/2	4.0	1/2	3.6	3/4	3.3
	1200	7.5	1/4	7.0	1/3	6.5	1/3	6.0	3/4	5.6	1	5.2
	1725	11.3	1/3	10.8	1/2	10.3	3/4	9.9	1	9.5	1 1/2	8.9
3/4"	900	10.3	1/2	9.8	3/4	9.4	3/4	9.0	1	8.5	1 1/2	8.0
	1200	13.8	1/2	13.3	3/4	13.0	1	12.6	1 1/2	12.0	2	11.9
	1725	19.9	1	19.6	1 1/2	19.4	1 1/2	19.0	2	18.5	2	18.0
1"	900	12.5	1/3	12.3	1/2	12.1	3/4	11.9	1	11.5	1 1/2	11.0
	1200	16.6	1/2	16.4	3/4	16.3	1	16.1	1 1/2	15.6	2	15.2
	1725	24.0	1	24.0	1 1/2	24.0	1 1/2	23.9	2	23.4	3	23.1

(*) RPM and GPM are in proportion; ie., at 860 RPM, pump output is approx. ... GPM figure for 1725 RPM.

SPECIFICATIONS AND ORDERING DATA FOR BRONZE PUMP HEADS

Pipe Size	Shaft Diameter	Shaft Height	H	W	L	Stock No.	List	Each
A BRONZE BEARING PUMPS WITHOUT RELIEF VALVE								
1/4"	1/2"	1 7/8"	2 3/4"	2 5/16"	5 7/16"	1P765	$101.17	$75.41
1/4	1/2	2 23/64	3 3/8	3	6 1/4	1P766	121.83	91.00
3/8	5/8	2 5/8	4	3 5/8	6 5/8	1P767	156.27	116.77
1/2	5/8	2 5/8	4	3 5/8	7	1P768	182.40	136.24
3/4	5/8	3 9/16	5 1/4	4	7	1P769	242.48	181.23
1	5/8	3 9/16	5 1/4	4	7 1/2	1P770	267.90	200.14
A CARBON BEARING PUMPS WITHOUT RELIEF VALVE								
1/4"	1/2"	1 7/8"	2 3/4"	2 5/16"	5 7/16"	1P771	$111.62	$83.13
1/4	1/2	2 23/64	3 3/8	3	6 1/4	1P772	134.90	100.84
3/8	5/8	2 5/8	4	3 5/8	6 5/8	1P773	179.78	134.12
1/2	5/8	2 5/8	4	3 5/8	7	1P774	202.58	151.13
3/4	5/8	3 9/16	5 1/4	4	7	1P775	264.10	197.34
1	5/8	3 9/16	5 1/4	4	7 1/4	1P776	286.18	213.83
B CARBON BEARING PUMPS WITH RELIEF VALVE								
1/4"	1/2"	2 23/64"	3 3/8"	3"	7 1/4"	1P777	$151.52	$113.05
3/8	5/8	2 5/8	4	3 5/8	8	1P778	218.02	162.54
1/2	5/8	2 5/8	4	3 5/8	8 3/4	1P779	292.30	175.13
3/4	5/8	3 9/16	5 1/4	4	8 7/8	1P780	308.5[illegible]	230.23
1	5/8	3 9/16	5 1/4	4	9 1/8	1P781	328.22	244.93

SPECIFICATIONS AND ORDERING DATA FOR CAST-IRON PUMP HEADS

Key	Pipe Size	Shaft Dia.	Shaft Height	H	W	L	Stock No.	List	Each
LIP SEAL MODELS									
C	1/4"	1/2"	1 7/8"	2 3/4"	2 5/16"	5 7/16"	1P825	[illegible]	[illegible]
C	1/4	1/2	2 23/64	3 3/8	3	5 1/4	1P826	102.12	[illegible]
C	3/8	5/8	2 5/8	4	3 5/8	5 5/8	1P827	[illegible]	[illegible]
C	1/2	5/8	2 5/8	4	3 5/8	5 3/4	1P828	[illegible]	[illegible]
C	3/4	5/8	3 9/16	5 1/4	4	5 3/4	1P829	[illegible]	[illegible]
C	1	5/8	3 9/16	5 1/4	4	6	1P830	[illegible]	[illegible]
PACKING SEAL MODELS WITH ZERK FITTINGS									
D	1/4"	1/2"	2 23/64"	3 3/8"	3"	6 1/4"	2P295	[illegible]	[illegible]
D	3/8	5/8	2 5/8	4	3 5/8	6 5/8	2P296	[illegible]	[illegible]
D	1/2	5/8	2 5/8	4	3 5/8	7	2P297	[illegible]	[illegible]
D	3/4	5/8	3 9/16	5 1/4	4	7	2P298	[illegible]	[illegible]
D	1	5/8	3 9/16	5 1/4	4	7 1/2	2P299	[illegible]	[illegible]