1986

Design principles for mechanically interfacing production equipment to material handling systems /

Richard Davis Jiranek
Lehigh University

DESIGN PRINCIPLES FOR MECHANICALLY INTERFACING PRODUCTION EQUIPMENT TO MATERIAL HANDLING SYSTEMS

by

Richard Davis Jiranek

A Thesis

Presented to the Graduate Committee

of Lehigh University

in Candidacy for the Degree of

Master of Science

in

Manufacturing Systems Engineering

Lehigh University

1986

Certificate of Approval

This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science in Manufacturing Systems Engineering.

Feb 3, 1986

Date

Professor in Charge

Director of the Manufacturing Systems Engineering Program

Chairman of Department

ACKNOWLEDGMENTS

My sincere thanks to Dr. Mikell Groover for his guidance and support in helping me complete this project. I would also like to thank the people at SI Handling Corporation for providing the material handling equipment in the Manufacturing Technology lab here at Lehigh.

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I Abstract

Although many material handling systems are developed to work as automatic-standard equipment, interfacing them to production equipment and other material transfer devices remains a custom engineered practice. This paper focuses on successful material handling interface design principles for specific equipment while supporting enough flexibility to allow for production changes and a natural integration to other manufacturing systems. A mechanical interface has been developed between a cartrack conveyor and a machining center to illustrate the specific principles. The hardware modifications to the conveyor cart have been completed.

II Introduction

Material Handling systems on the factory floor serve important functions for production from shipping to receiving. In the past, material handling has been accomplished manually with the aid of tow motors and push carts. Work-in-process inventories were large to accommodate inconsistent production rates and factory shop floor scheduling problems. Today, the trend of material handling is towards automatic-programmable transfer and vastly reduced work-in-process inventory. This new streamlined approach is mainly due to the programmable controller and on-line information systems.

Apple and White [1] have developed a long range overview for material handling system requirements. They point out that handling systems are more complex due to advanced requirements from other manufacturing systems for successful factory integration. Traditional material handling concentrates on point to point motions whereas new high tech factories require programmable moves. Workstations in the factory must be provided with work under reduced manual handling conditions. Inspections and quality audit operations must be designed into the automated material flow path.

Today, the rates of product and manufacturing system changes require that systems become more flexible, universal, and cost effective. When short-lived products are anticipated, consideration should be given to very flexible systems which consider load size, sorting ability, dispatching requirements, and delivery schedules. For example, machines are initially installed for convenient access for part loading; however, as machines are replaced, the material flow pattern is interrupted thus requiring additional material handling movements and interface requirements.

Both material handling systems and production equipment have been developed to the point where they can operate automatically as turnkey systems. However interconnecting these two systems remains a custom engineered interface.

A literature search was conducted through the Engineering and Science Index and through the Materials Handling Institute to determine what work has been done in standards development. Nothing was found that addressed design principles for the mechanical interfaces. It appears that successful interface attempts have always been custom engineered for a specific application.

As an example of the absence of interface standards, a local manufacturing company interfaced their Cart-on-track system to Kearney & Trecker CNC machining centers. In the factory, all of the machining centers were arduously installed at the same height and the system could not interface with any other workstations, making the system unnecessarily specialized. Factories in the future that hold the flexibility that everyone dreams of will be able to change and move production equipment around as requirements change with a minimal effort. This is the major goal of the flexible interface developed here.

III Statement of Problem and Scope

III.1 Methods of Interfacing

There are three basic ways of achieving the interface between material handling systems and production equipment: robots, custom interfaces and standard interfaces. Pick and place robots can be used to integrate two systems together but specialized handling mechanisms prove to be less expensive for this application generally. At automatic robotic assembly stations however, the same robot used to assembly the parts may be used successfully to transfer a palletized part container onto the assembly station.

Custom interfaces are built specifically for one type of material handling system and one type of production equipment. It normally requires installation of production equipment at specific table heights so that the material handling system can service it. A way of transferring the parts must be developed and the systems are usually not applicable to other types of production equipment.

Standardized interfaces require that the material handling system have built-in flexibility to service different types of production equipment. Standardized tracks leading to the production table and standardized clamping devices are common to all workstations.

III.2 Interface Goals and Challenges

Material handling systems must be mechanically interfaced to production equipment for automatic-unmanned operation. The interfaces should be designed to achieve the following goals:

- -flexibility for changing products, equipment, and production rates
- -fast operation
- -reliability
- -fast interface installation time
- -easily installed by unskilled laborers
- -safe operation
- -and, cost effectiveness

Features which promote increased overall system flexibility and usefulness are:

- -proper buffer design between material handling system and production equipment
- -integratability to information tracking and control systems

-and, the ability to allow for human intervention in manual operations.

Flexibility appears to be becoming a more and more important goal in future factories. Many factories today must be able to adapt to changing products and process developments to survive in the future. The trend towards reduced product life cycle (obsolescence) threatens the long term existence of factories that are not flexible to changing products more than in the past.

An integrated material handling system must maintain a level of flexibility similar to other manufacturing systems in the factory. However it is difficult to establish a quantitative definition of flexibility. It does seem practical to require that the material handling system be able to accommodate a range of different products with similar processing steps. For example, a single material handling system should not be expected to service silicon wafers and cast iron engine blocks. Rather, a single material handling system should be expected to service all parts that are manufactured by metal removal machines with some flexibility to other production and material handling equipment.

Changing production rates pose a significant problem to material handling systems-typically when new and different products are introduced into the manufacturing system. Discrete handling systems such as AGVS and Cart-on-track systems, carry single loads whether they be individual or palletized parts. Slight changes in production rates can be accommodated by increasing or decreasing the number of carriers. But, if the throughput in production is increased by an order of magnitude, it may seem infeasible to increase the number of carriers by the same amount because of economics and traffic congestion problems.

Another challenge towards flexibility is the number of different process stations the material handling system can accommodate. The system should service production equipment at various table heights. In Apple Computers' Macintosh personel computer plant, all of the machine tables were installed at the same height by varying the floor pad height. This was done just so the automatic handling system could service them all. This is probably not a viable solution for the factory that anticipates changing production equipment to meet new product demands or to take advantage of new processing technology. Therefore the carrier height on the material handling system should change automatically to accommodate a range of machine table heights.

Also, some production equipment requires that parts be delivered more accurately than others. And in some instances to more accurate tolerances than the material handling vehicle can deliver. This is another common problem that the mechanical interface must solve.

Proper buffer design at the handler/machine interface improves the efficiency of both systems. For unit load handling systems, a buffer with at least two part positions is recommended . A one position buffer (figure 1a) requires that when the production equipment has finished a part task, an empty handler must arrive and pick the part up and another handler must then deliver a new part. With a 2 position buffer (figure 1b), a single unit handler can unload a part onto the production equipment and pick-up the part just completed. And a 3 position buffer (figure 1c) may prove to be the most effective because it allows a part to wait in queue for either the production equipment or the unit handler [2].

It was mentioned that the mechanical interface must be efficient, reliable, safe, and cost effective. This of course is realized through a sound mechanical design. Specific attention has been directed towards simplicity and reduced parts in this application.

III.3 Economic Analysis of Standard Verses Custom Interfaces

Economic value is the most important criteria of all in measuring the success of any project. The economic

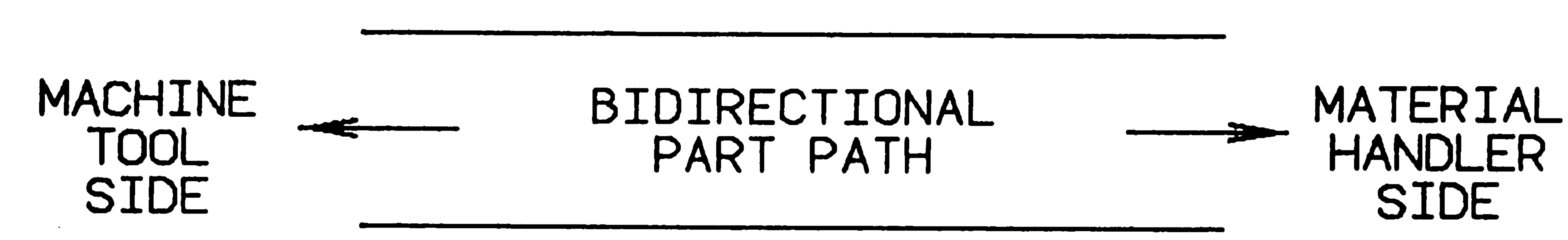

FIGURE 1A - 1 POINT BUFFER

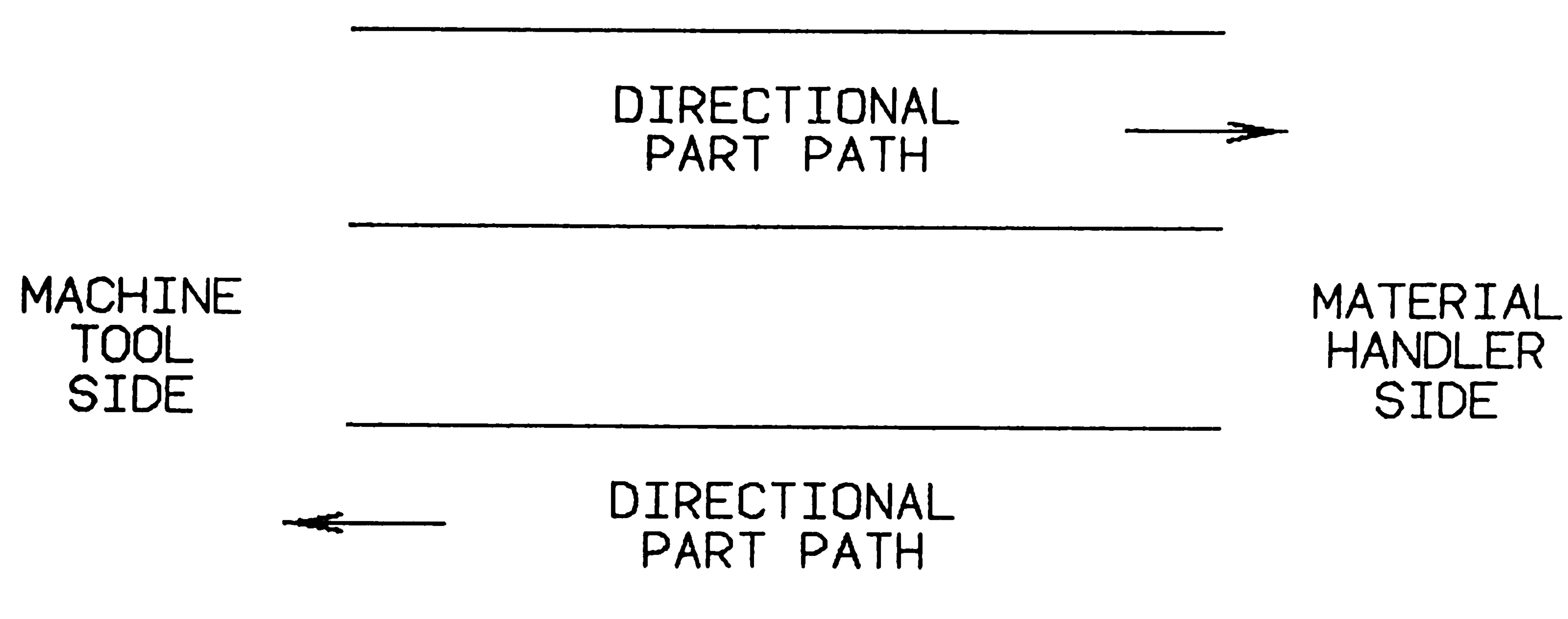

FIGURE 1B - 2 POINT BUFFER

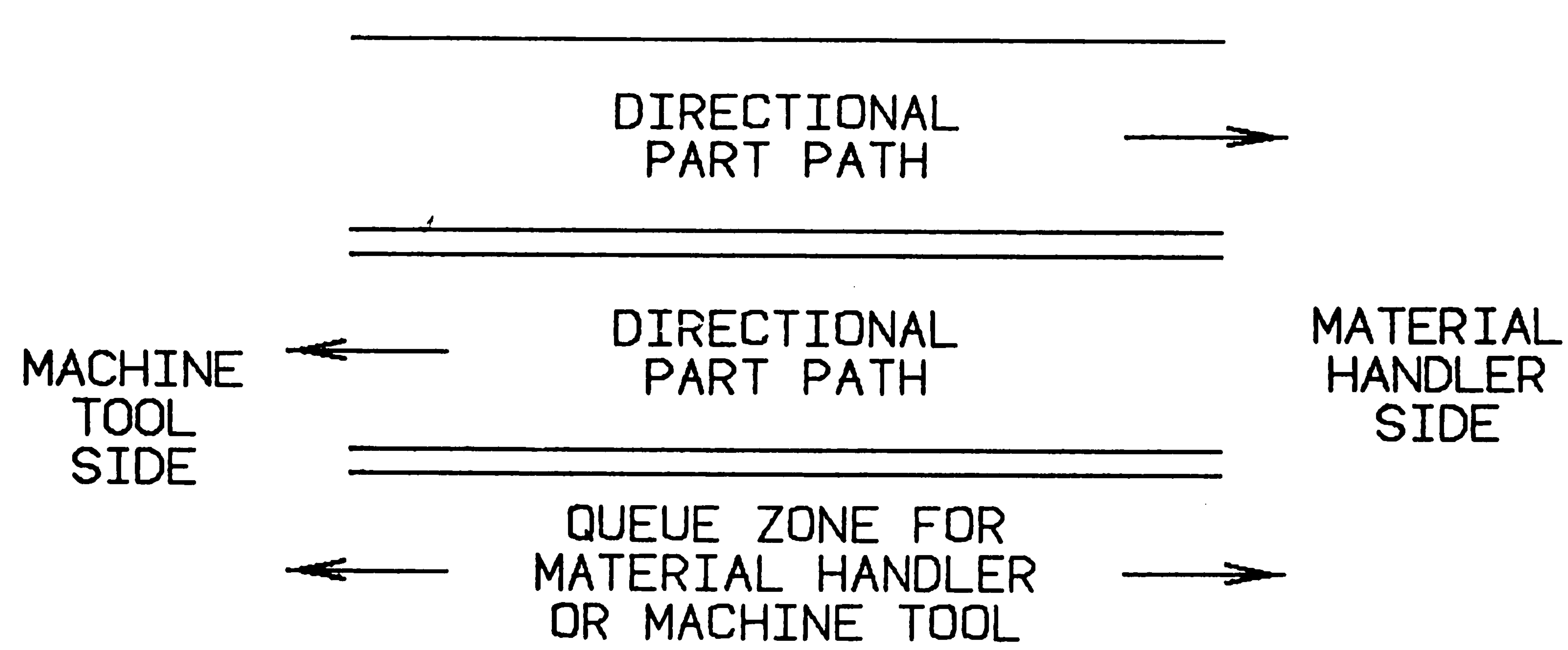

FIGURE 1C - 3 POINT BUFFER

FIGURE 1 - BUFFER DESIGN

issue in this example of mechanically interfacing one piece of equipment to another is probably going to be different for each specific application. Three areas are identified that will cause different analysis depending on a specific factory's characteristics: flexibility required, number of workstations compared to number of unit handlers, and the value of time that is necessary to install the interface. Other associated costs are the engineering cost of design and production cost.

Equations 1 and 2 have been developed to show the relationships between custom engineered interfaces and standardized interfaces.

$$CC = Y [NW (CCE + CBC + VTC)] \quad \text{(Eq. 1)}$$

where:

CC = total cost of custom engineered interface

Y = a flexibility factor

NW = number of workstations

CCE = engineering cost of developing custom work station interface

CBC = cost of building custom interface

VTC = value of time spent designing custom interfaces

$$CS = Y [CSE + NUH (CBS) + VTS] \quad \text{(Eq. 2)}$$

where:

CS = total cost of standardized interface design

CSE = engineering cost of developing cart modifications

NUH = number of unit handlers

CBS = cost of building standard interface

VTS = value of time spent designing standard interface

An explanation which further defines some of the equation terms will follow. The flexibility factor (Y) pertains to the usable life of the mechanical interface. This factor is intended to relate to the inverse of the interface's lifetime. For factories that make the same product day in and day out and intend to do so for a long time with the same machinery, the flexibility factor will be low for custom interfaces because the interfaces will last a long time. However, for factories that anticipate changing demands resulting in changing production equipment, the flexibility factor can only be low using standardized interfaces because they will have an extended usable lifetime. The costs of engineering work (CCE & CSE) refer to design costs, fixturing and tooling development costs, operations programming, and employee training. The costs of building the interface (CBC & CBS) are the material and labor costs involved in making and installing the mechanical interface. And finally, the value of time (VTC & VTS) are somewhat abstract, but they refer to the time spent designing and installing the interface once the decision has been made to install a piece of production equipment. The value of time can be thought of as either (1) lost production because the machine may be installed but the interface is not yet working, or (2) the lost engineering capacity to do developmental work rather than routine interface designing.

It is anticipated that the time spent on standard interface design will be far less than for custom interfaces. Which means that engineering costs and the value of time will be significantly less expensive.

III.4 Interface Problem at Lehigh's Manufacturing Technology Lab

This thesis deals with a generic-flexible interface system developed out of a project interconnecting a cartrack (spinning tube conveyor) to a CNC machining center. The features of this system make it possible to also mechanically interface Automatic Storage and Retrieval Systems (ASRS), Automatic Guided Vehicles (AGV's), assembly stations and other associated production equipment. Two key characteristics of this system which allow for flexibility are locating accuracy and variable carrier heights for pick-up and delivery.

A modular approach has been used to realize the many aspects of flexibility previously mentioned. The project design has included a carrier bed of rollers in which any flat surface can be transferred (ie. tote pans and modular fixture bases). The modular fixture base was developed as a common building block to standardize clamping on machine tools with an automatic vise. Standardized bases (or cassettes) are often used to hold parts for assembly stations to assemble components that must be positioned accurately [3].

IV Project Solution at Lehigh's Manufacturing Technology Lab

IV.1 Functional Overview of Interface

The mechanical interface developed for use in the Manufacturing Technology Lab is pictured in illustration 1. The concept begins with a modular base that serves as a standard for production equipment. Many companies have begun to realize the benefits of modular base pallets and building block fixture plates. The base plates (illustration 2) normally have a grid pattern of alternating locating and tapped holes.

The base plate has an optional feature that accurately guides the plate during delivery to the production equipment. The angular bar (illustration 3) is guided by successive rollers that have a narrowing "V" notch. The

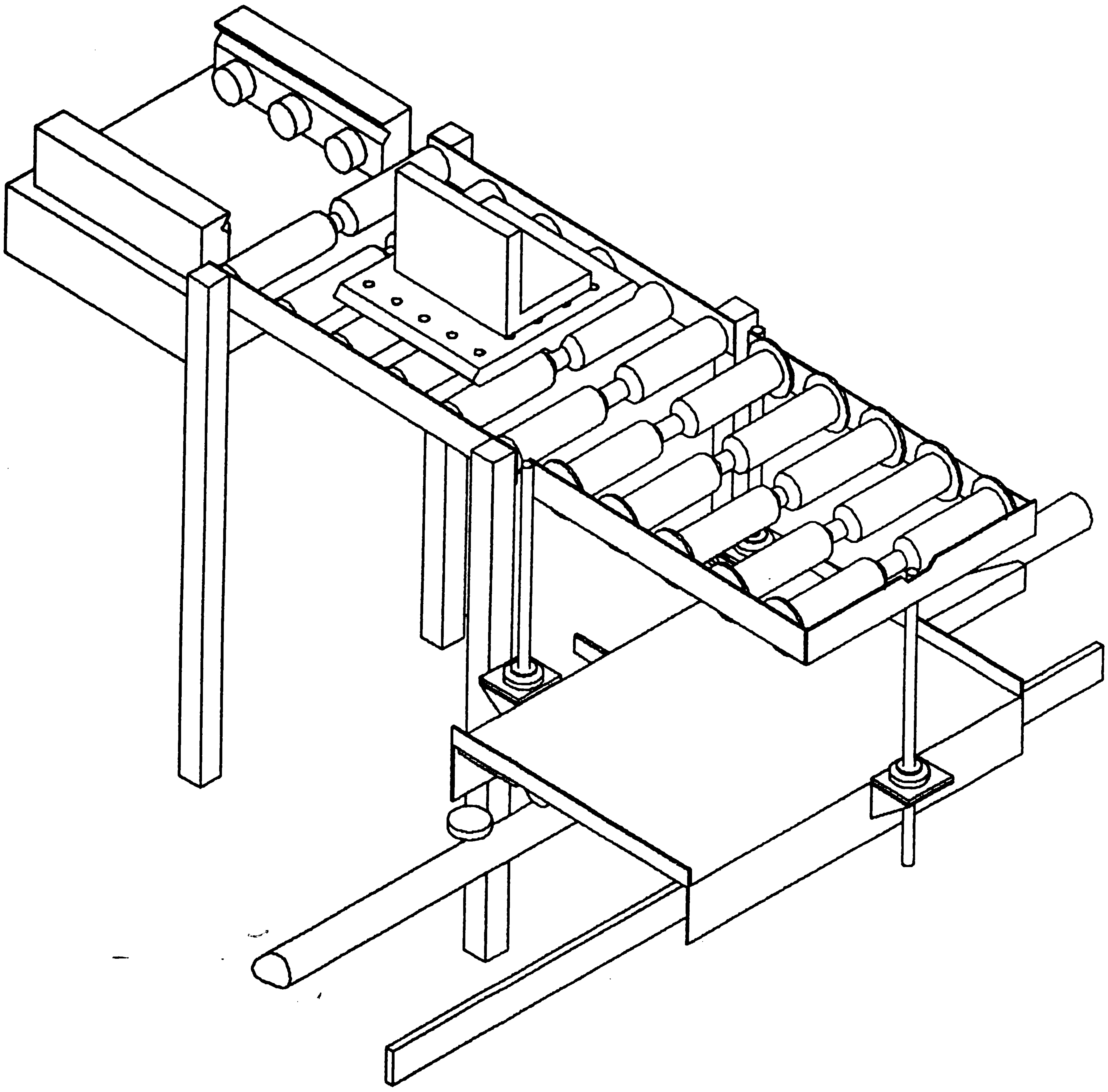

ILLUSTRATION # 1. MECHANICAL INTERFACE

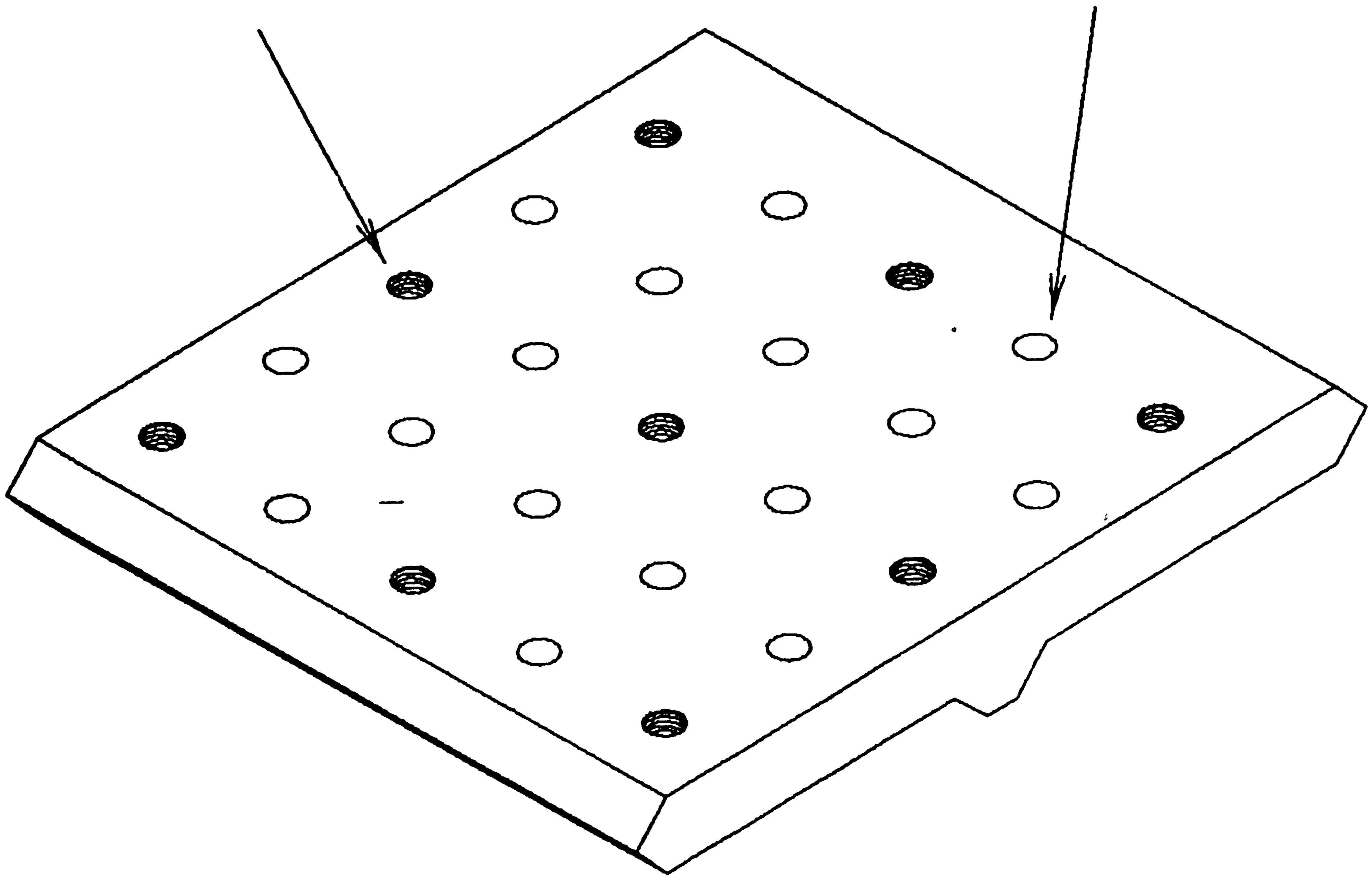

ILLUSTRATION 2. BASE PLATE

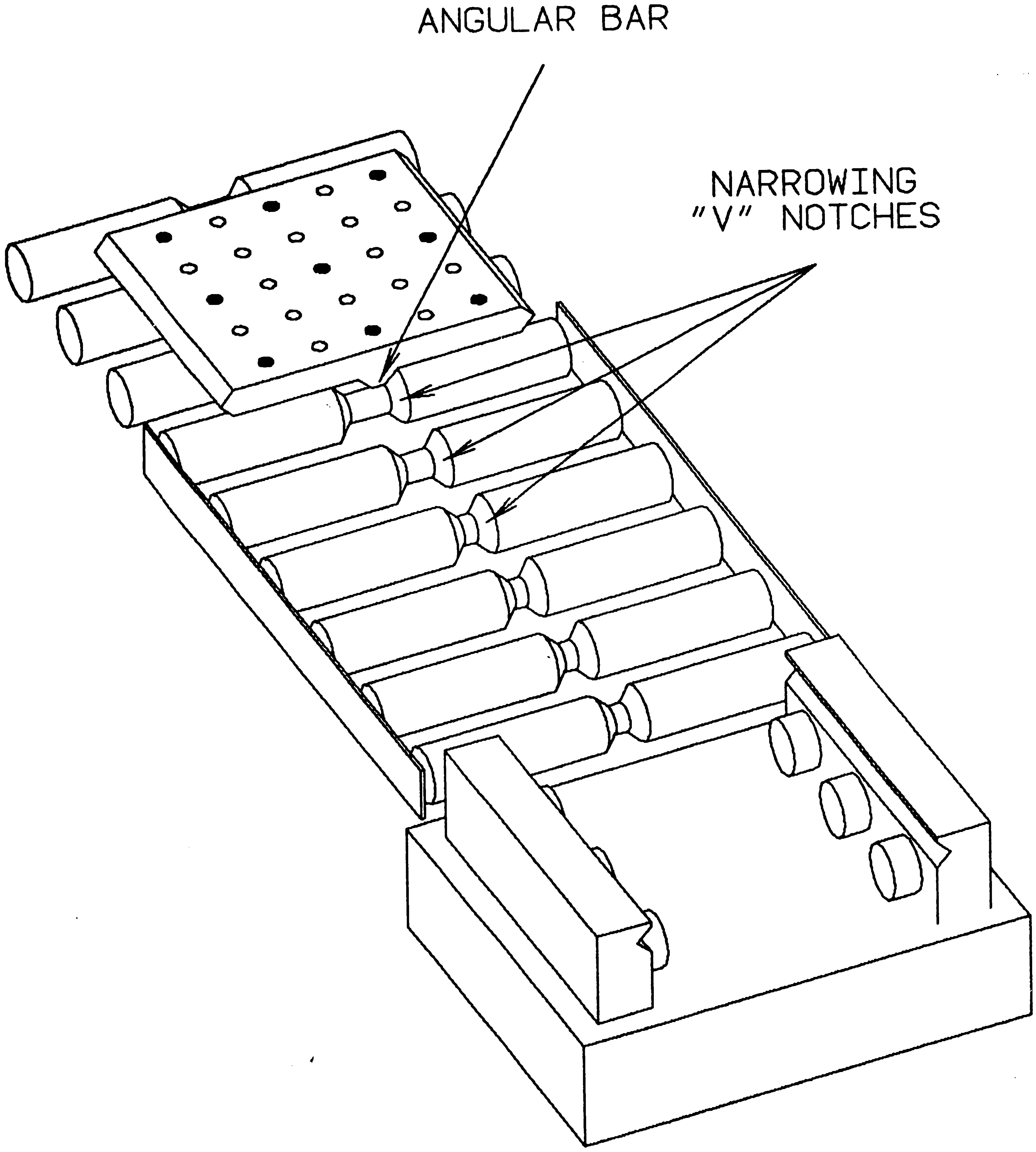

ILLUSTRATION 3. ANGULAR BAR CONCEPT

angular bar concept eliminates guide bars on the sides which are inflexible to different size plates and must be custom engineered to each application. Note: the design is not limited to this optional base plate configuration. Tote pans and other flat items are easily accommodated. Belts can be installed over rollers for uneven parts.

The guiding feature will be required whenever the material handling system's ability to deliver parts is less accurate in terms of location than is required by the production equipment. For example, the location accuracy of a fixture on a cartrack may be + or - 1", partially because of the cartrack repeatability (+ or - 3/8") and the loading variations of the fixture onto the material handling system. The fixture would need to be guided into the vise for the CNC machining center requiring a + or - .1" tolerance.

The modular base plate can be conveniently clamped by an automatic vise (see illustration 4). The two sides of the plate are tapered to clamp from all directions and to lift the plate off the rollers (say .05"). Air jets to wipe the clamping surface free of foreign matter should be considered.

The rollers pictured on the cart-on-track (illustration 1) move vertically to interface with different workstations with varying height. This eliminates

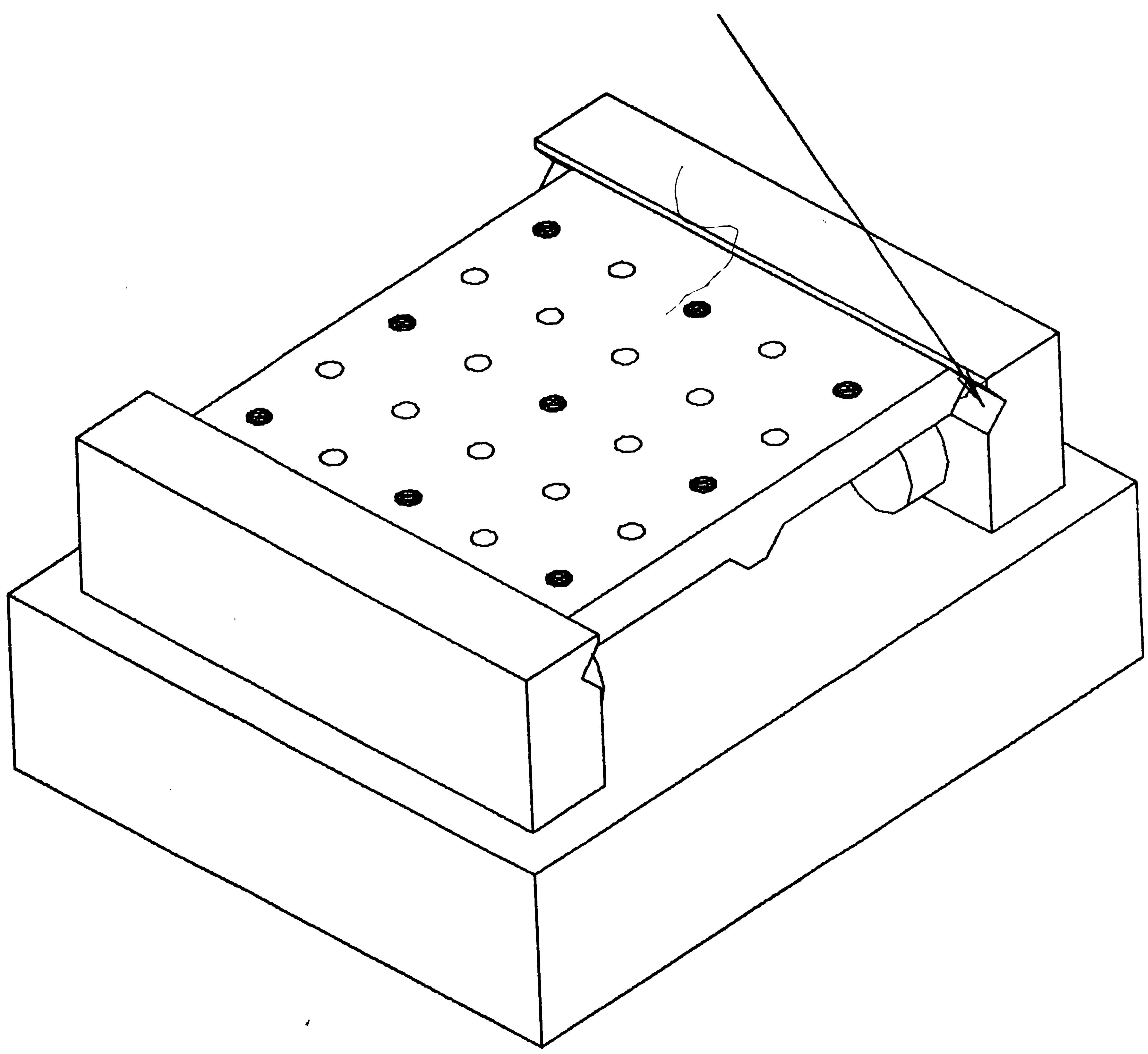

ILLUSTRATION 4. AUTOMATIC VISE

the need to build factory floors with pits and pedestals to accommodate varying machine tool table heights. (Note: there appears to be no incentive for the machine tool industry to adopt a standard for table heights.)

IV.2 Specific Interface Operation of Modified Cart

The cart will perform normally during transport to the workstation. Under the new modifications for automation, however, the cart will arrive at its destination point; four solenoids (illustration 5) will control the carrier height and the roller rotation. All of the power transmission is from the spinning tube while the controls are located offboard of the Cart-on-track and on the workstation. This is required because the carts do not have any type of active control system. (Their programmed starts and stops are accomplished with mechanical stops in the track.)

Lever 2 is engaged to raise the carrier top while lever 3 lowers it. Lever 1 powers the rollers forward and lever 4 powers the rollers backwards. When the levers are not engaged, Chain breaks prevent the load from slipping.

A sample part delivery routine will perform the following steps: the cart will arrive at the workstation with its load in the low position (for stability and safety during travel). Lever 1 will be engaged to raise the load. Illustration 6 shows a binary switch that changes state ..

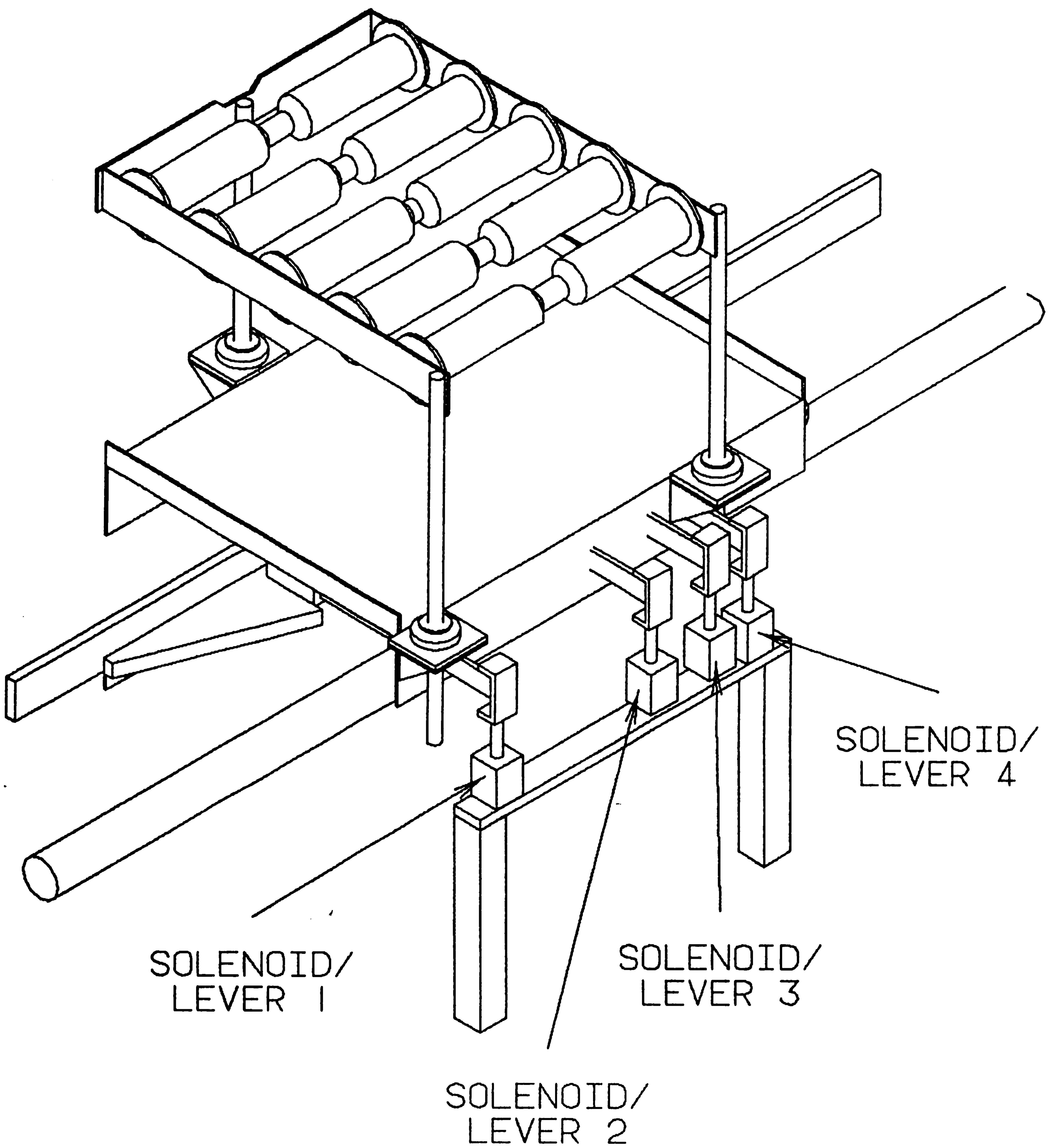

ILLUSTRATION 5. SOLENOID ACTIVATORS

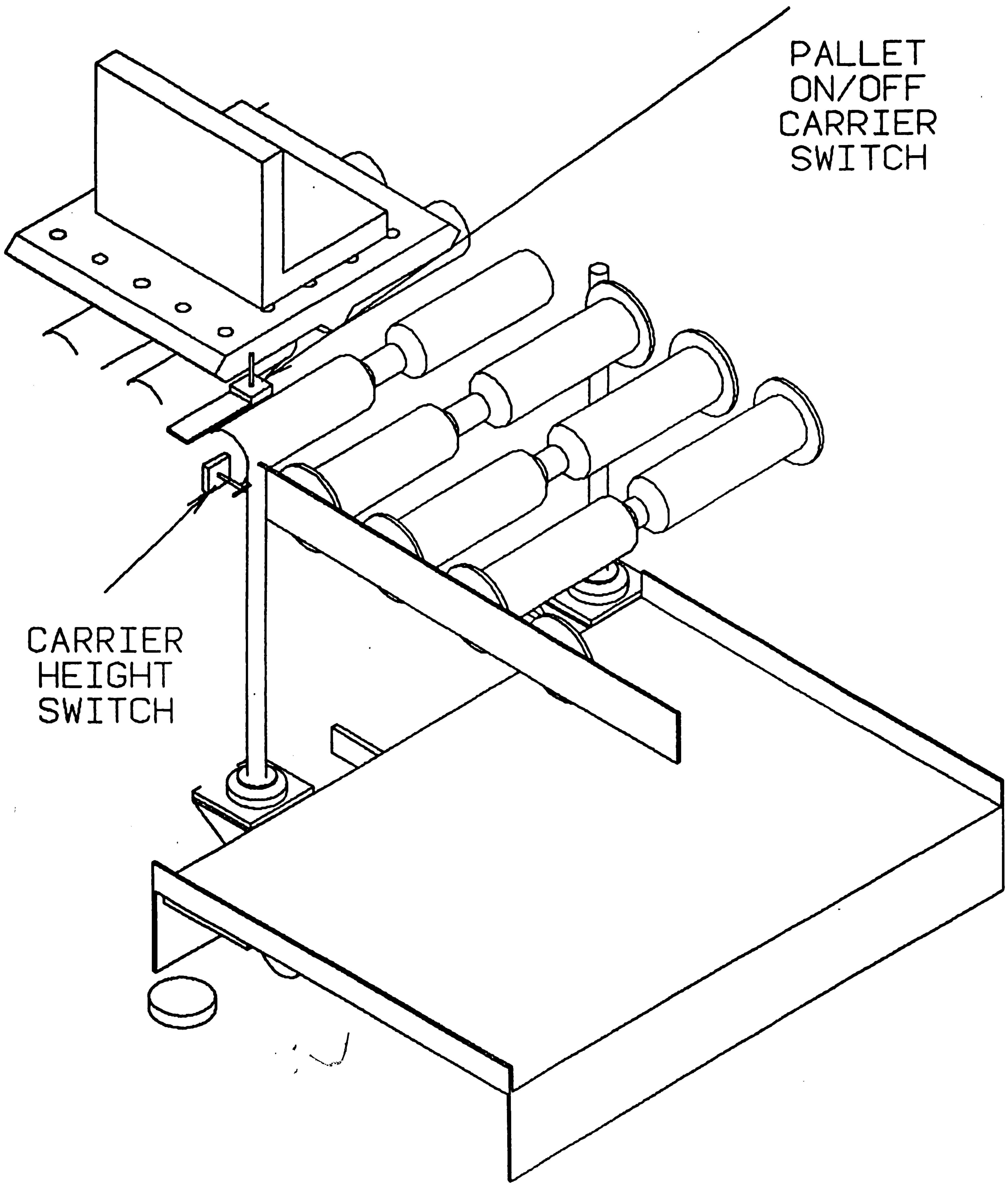

ILLUSTRATION 6. SWITCH LOCATION

when the rollers reach the proper height. The solenoid engaging lever 2 is disabled thus engaging the chain break to prevent slippage. Lever 1 is then engaged to drive the pallet off the Cart-on-track carrier bed until another binary switch (illustration 6) senses that the pallet is off. Lever 3 is then engaged to lower the rollers for departure. (note that Lever 4 was not used because this example delivered a pallet and did not pick one up.)

IV.3 Detailed Design of Interface

Illustrations 7 & 8 show a top and an underside view exposing the mechanisms that transmit power from the spinning tube to the carrier top. A listing of each part, starting from the rollers and working down, will follow with a functional description included. (Note: it is assumed that the reader is familiar with the design and operation of the Cart-on-track or spinning tube conveyor system. If not, information can be obtained by contacting SI Handling Systems Incorporated, Easton, Pennsylvania 18042.)

1. Roller Centers - converging cylindrical "V" notches. Made of aluminum and are press fit into Steel Pipe Rollers.
2. Steel Pipe Rollers - 2" Schedule 10 thin walled pipe.
3. Pipe Ends - Delron plastic material also serves as

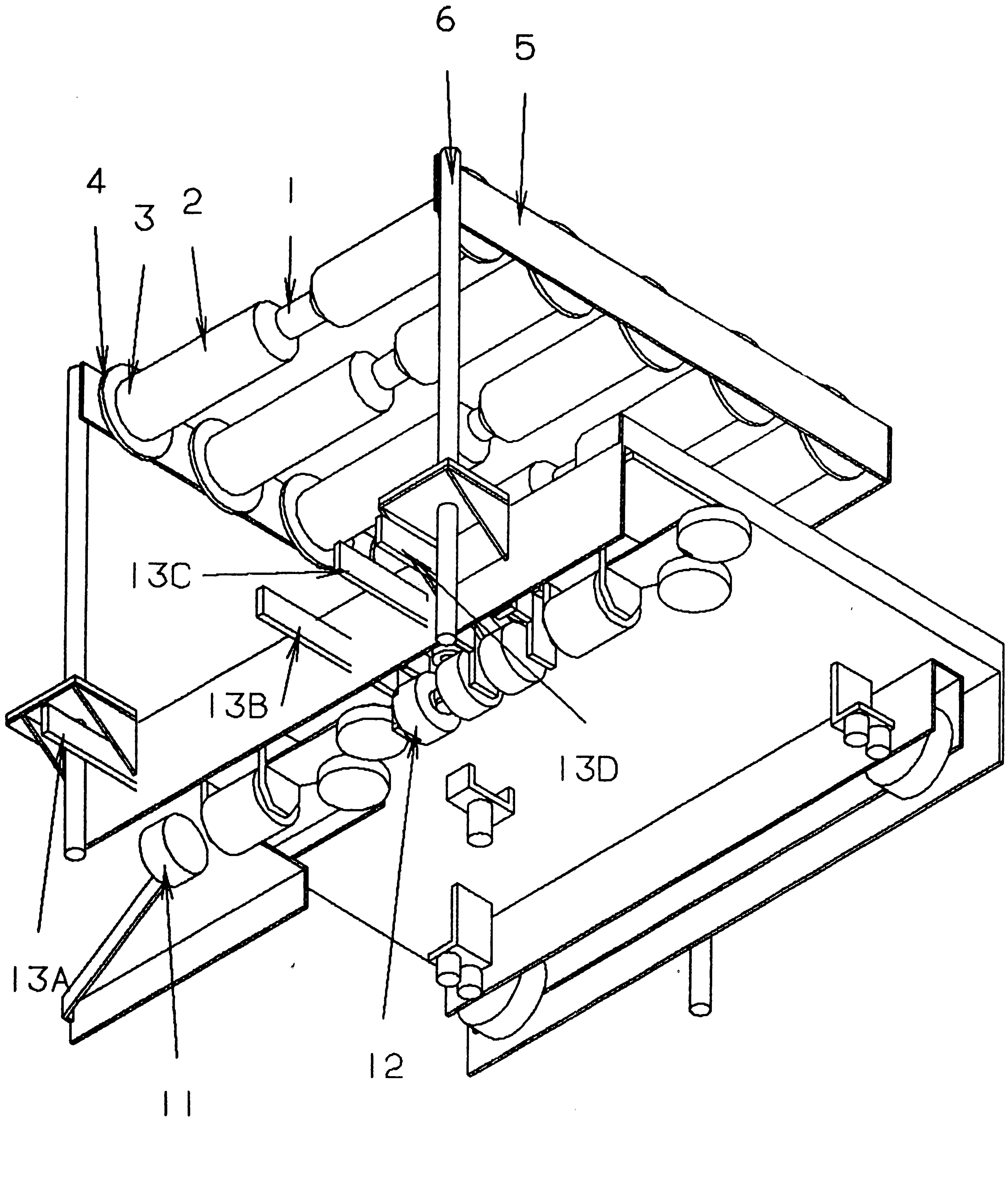

ILLUSTRATION 7. UNDERSIDE VIEW OF CART

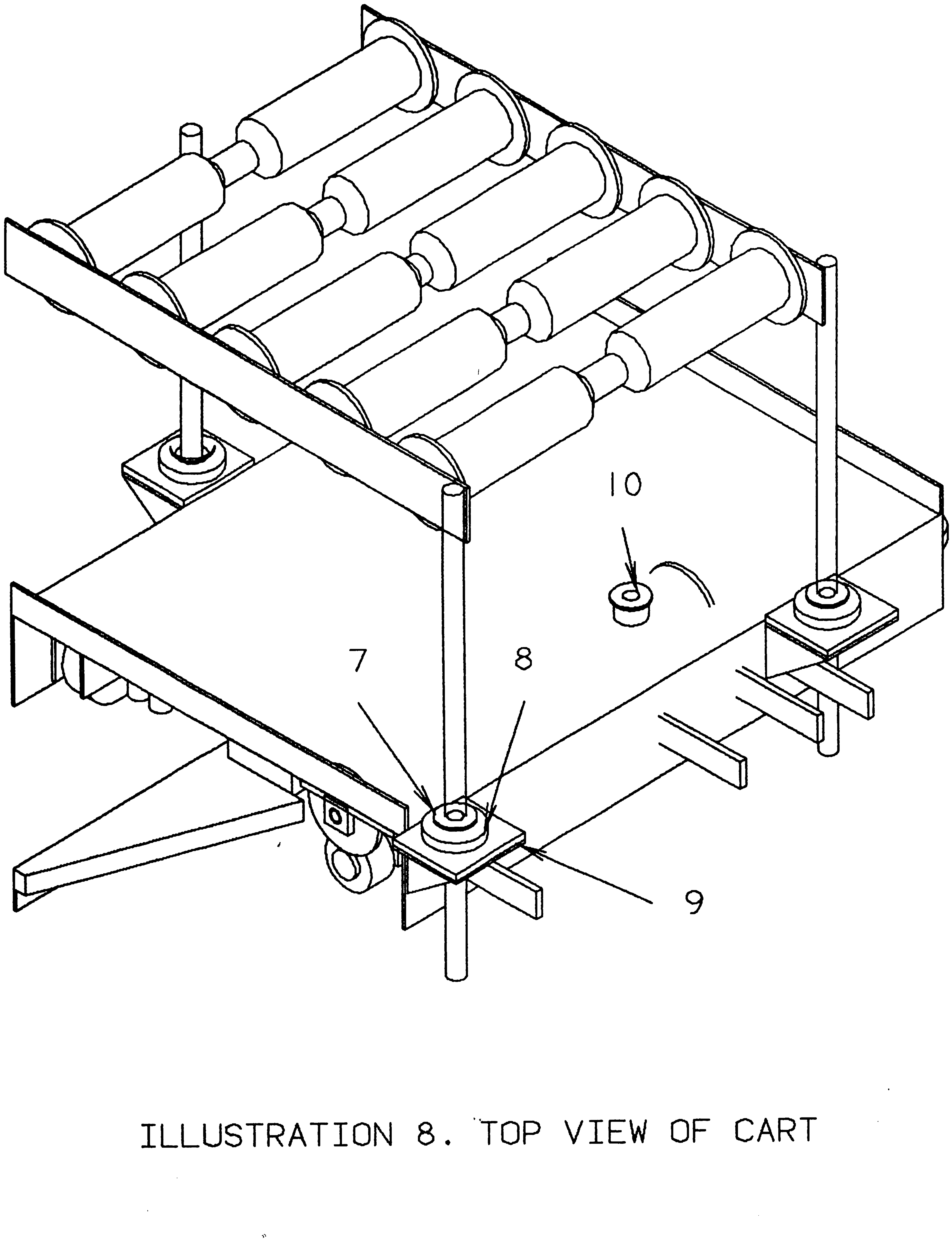

ILLUSTRATION 8. TOP VIEW OF CART

bearing surface (Boston (*) part # 16P10D-1/2).

4. Chain Sprockets on Rollers - 3.111 inch # 35 3/8" pitch. (Boston part # 35A26)

5. Roller Frame - 1/8" x 2" steel plate with 1/2" pins located every 4" for roller support.

6. Screw Drive Assembly - thread screw and ball nut (6A on illustration 7) for elevation control of carrier height (Saginaw Steering Gear (**) part #'s 5707540 - thread screw and 7820827 - ball nut).

7. Chain Sprocket on Screw Drive (illustration 8) - 1.331 inch # 35 3/8 pitch (Boston part # 35B11-1/2).

8. Bearing for Screw Drive Assembly - radial and thrust combination bearing (Boston part # 515).

9. Screw Drive Bearing Support - plate steel is welded to standard Cart-on-track top.

10. Chain Sprocket for Vertical Transmission - 1.331 inch # 35 3/8 pitch (Boston part # 35B11-1/2).

11. Horizontal Transmission Assembly - for forward and backward roller rotation. (assembly and part #'s on illustration #9).

A. Drive Gear on Neoprene Roller - 32 diametral pitch 1" diameter spur gear used for gear reduction (Boston part # H3232).

* Boston Gear, Incom International Corp., 14 Hayward St., Quincy, MA 02171.
** Saginaw Steering Gear Div. General Motors Corp., Saginaw, MI 48605.

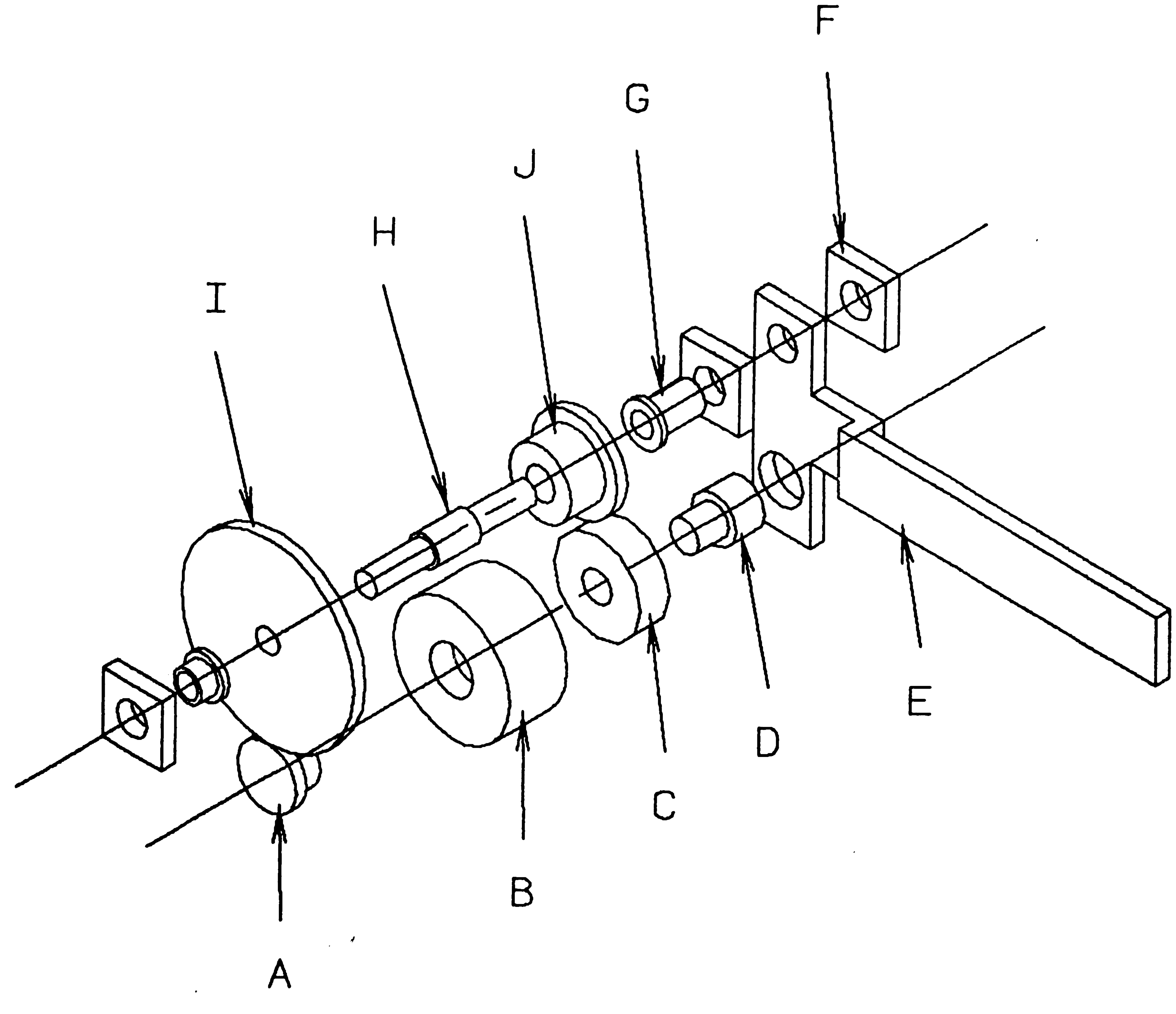

ILLUSTRATION 9. HORIZONTAL TRANSMISSION

B. Neoprene Roller With Steel Sleeve - 90 durometer hardness used to spin directly on cartrack spinning tube and serves as clutch.C. Bearing - radial ball bearing is press fit into Neoprene Roller Sleeve (Fafnir (***) part # 7513).

D. Shaft - connects bearing to swing arm.

E. Swing Arm - used as clutch to engage Neoprene Roller on and off of spinning tube.

F. Mounting Bracket - to hold transmission assembly to cartrack.

G. Bronze Bearing Sleeve - oil impregnated sintered bronze (Boston part # FB68-7). Note, this bearings capabilities are used to satisfy two separate bearing functions. The inside surface is for the Shaft (H) and the outside surface is for the Swing Arm (E).

H. Shaft - supports Spur Gear (I) and Chain Sprocket (J).

I. Spur Gear - 32 diametral pitch 3" diameter used in gear reduction to drive Chain Sprocket (J) (Boston part # H3296).

*** Fafnir Bearing Div. Textron Inc., 37 Booth St., New Britain, CT 06050.

J. Chain Sprocket - 1.331 inch # 35 3/8 pitch sprocket used for horizontal roller motion (Boston part # 35B11-1/2).

12. Vertical Transmission Assembly - for up and down motion of carrier top. (Assembly and part #'s are on illustration # 10.)

A. Mounted Radial Bearing - holds Vertical Shaft (B) in between the two Vertical Transmission clutch assemblies (Boston part # N6908).

B. Vertical Shaft - supports chain sprocket and Miter Gears (C).

C. Miter Gears - 32 diametral pitch 3/4 inch miter gear used for transferring horizontal power to vertical power. Two on either side, spinning the . same direction, turn the vertically mounted one in opposite directions (Boston part # L96Y).

D. Neoprene Roller with Steel Sleeve - 90 durometer hardness is used to spin directly on Cart-on-track spinning tube.

E. Bearing - radial ball bearing is press fit into Neoprene Roller Sleeve (Fafnir part # 7513).

F. Shaft Connecting Bearing to Swing Arm.

G. Swing Arm - used as clutch to engage Neoprene Roller on and off of spinning tube.

H. Mounting Bracket - to hold transmission to ..

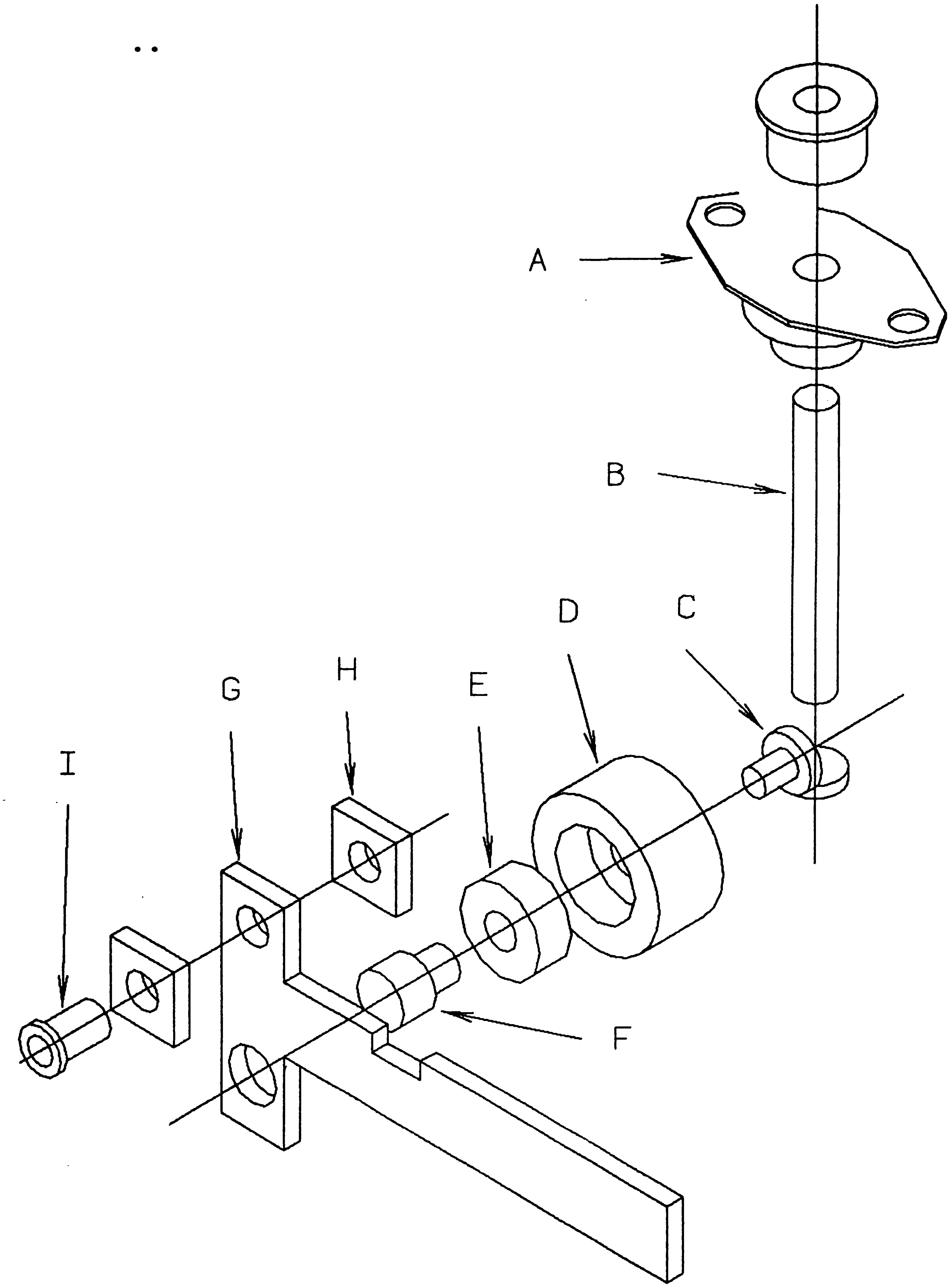

ILLUSTRATION 10. VERTICAL TRANSMISSION

cartrack.

I. Bronze bearing Sleeve - oil impregnated sintered bronze (Boston part # FB68-7).

13A. Control Arm (Lever 1) for 1st Horizontal Transmission - forward roller rotation.

13B. Control Arm (Lever 2) for 1st Vertical Transmission - rising carrier top motion.

13C. Control Arm (Lever 3) for 2nd Vertical Transmission - lowering carrier top motion.

13D. Control Arm (Lever 4) for 2nd Horizontal Transmission - backward roller rotation.

V Future Work

V.1 To Complete Interface System

The cart modifications are complete, except that chain take-ups and brakes must be designed and built for the forward and backward rotation of the roller on the carrier top. The chain take-ups/tensiometer design is not trivial. This part of the design was left for future work partially because consideration for the take-up is dependent on the range of vertical motion. For example, one configuration might be considered for travel between 6" and 15" (above standard cart height) and another configuration will accommodate travel between 10 and 28 inches.

The completion of the chain take-ups and brakes will finish the necessary cart modifications, however the rest of the interface to the machine tool has not been built. Three main components of this interface consist of: the cart control section, the track or path to the machine tool, and the clamping fixture. These components should be similar to every workstation project.

The cart control section must be able to activate the four control levers that raise/lower the carrier and rotate the rollers forward/backward. The author envisions four solenoids lined up providing the up and down motion required to activate each clutch and is pictured in illustration # 5.

Illustration # 1 shows the track or guide path leading to an automatic vise on the machine tool. The rollers on this path will have to be powered in both directions and the vise should automatically clamp hydraulically. (Actually, hydraulics normally unclamp a spring loaded vise. This way a leaky hydraulic cylinder will not loosen the vise.)

V.2 Future Enhancements

There are several enhancements that could be installed to increase the interface performance and overall integration with other manufacturing systems. The solenoid activated cart controls could be interfaced with sensors and the material handling system controller to gain added centralized control and assurance of operation.

The interface between the material handling system and associated production workstations is a desirable location for an information control node to a factory's planning and control system. There are many methods for reading and writing information on parts for automatic identification.

Narasimhan and Koza [4] have described the pros and cons of three categories of identification systems which are suitable for future factories. Optical character recognition devices remain to be unpopular because they require specialized equipment and are very sensitive to dust. However, light pens, fixed beam, and moving beam readers are sometimes used as identification devices. Magnetic stripes and characters (bar codes) are not affected by dirt and grease and can operate at higher densities than optical readers. Also, they can be readily changed to record new information. Magnetic stripes are read by slot readers and hand held devices. Electronic encoding techniques constitute the third category and consist of rf transmitters radiating signals in the microwave range to transponders attached to the product. A transponder can send or receive signals as well as add or change encoded information. Complete manufacturing records can be retained without using a computer during the production process. It is expected that the distance from the source to transponder will be up to 6 feet. Electronic encoding techniques are resistant to extremes of cold, vibrations, heat, moisture, and mechanical stresses.

V.3 Maintenance and Repair

The nature of this prototype interface calls for routine lubrication checks and repairs can be difficult. Production units could be made with maintenance free materials and assembly methods could ease repairs should they be necessary. For reasons of limited budget resources, these alternatives were not employed. Rather the emphasis was made in the operation of the mechanism.

In actual production, timing belts and lubricant impregnated plastic gears, such as Teflon filled Acetyl, should be substituted for the chain drive and transmission gears.

V.3.A Maintenance Schedule

Item	Frequency
Roller Bearings	Maintenance free
Chain	Clean and relubricate every 25 hours operation with dry lubricant such as Teflon/lithium grease.
Gear Drives	Clean and relubricate every 10 hours operation with similar lubricant as above.

V.3.B Repairs

Most of the Cart-on-track interface can be repaired with little difficulty. However, there are sections that may require breaking welds to get parts out. This is obviously an undesirable feature, but part selection was limited in this prototype - forcing the "undesirable design".

Transmission disassembly - remove miter or spur gear by loosening set screws in Neoprene roller and spacer (see illustration # 11). Knock out wedge with a pin through pilot hole in swing arm being careful not to put too much strain on the transmission mounting brackets. Pull Neoprene roller sleeve off of shaft. At this point, the transmission can no longer be disassembled any further without destroying other parts. The shaft in illustration # 11 prevents this because it can't slide through the 3/8" bronze bearings. If further disassembly is required, it is suggested that the shaft be cut in half through the sprocket and be replaced with a 3/8" shaft with a collar and set screw to make up the 1/2" portion of the original shaft.

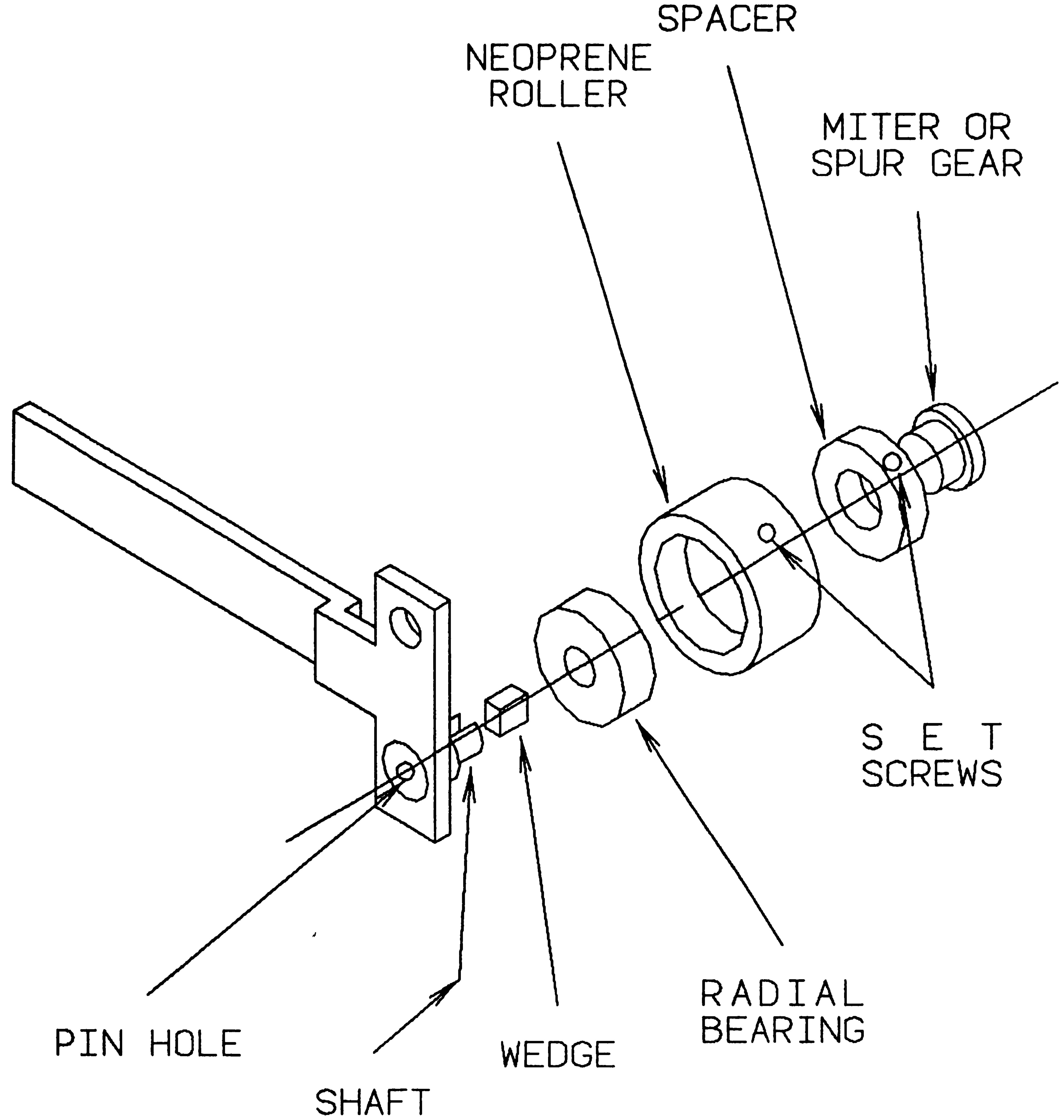

ILLUSTRATION II. TRANSMISSION DISASSEMBLY

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VII Appendix

VII.1 Vita

Richard D. Jiranek was born in Allentown, Pennsylvania on March 29, 1960. He has also lived in Connecticut and Minnesota. Graduating from Lehigh with a B.S. in Chemical Engineering, he found work with Computer System Products in Minneapolis. Returning to Lehigh in 1984, he expects to receive his Masters in Manufacturing Systems Engineering in 1986.