PAVEMENT CRACK AND JOINT SEALING AUTOMATED MACHINE

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ABSTRACT

The sealing and filling of cracks in highway pavement are maintenance activities that are routinely performed throughout the world to extend the time between major rehabilitations. These activities are extremely labor intensive, tedious, dangerous, slow, and costly. Accordingly, the Strategic Highway Research Program (SHRP) has supported the H-107A project to develop machinery to perform these tasks in an automated manner. This two and one-half year project is approximately half over, and this paper reports on the progress to date. This includes discussions of the development plan, the overall machine architecture that includes seven primary subsystems, how the machine will address pavement cracks, and design aspects and status of the seven subsystems.

INTRODUCTION

Worldwide, a tremendous amount of resources are expended annually maintaining highway pavement. In California alone, the state Department of Transportation (Caltrans) spends about $100 million per year maintaining approximately 33,000 lane-miles of flexible pavement (Asphalt Concrete - AC) and 13,000 lane-miles of rigid pavement (Portland Cement Concrete - PCC). A portion of these maintenance activities involve the sealing and filling of cracks (approximately $10 million per year). The purpose of crack sealing and filling is to prevent the intrusion of water and incompressibles into the crack, while crack filling is additionally used to hold broken pieces of pavement together. When properly performed, these operations can help retain the structural integrity of the roadway and considerably extend the time between major rehabilitations.

The sealing and filling of cracks are tedious, labor-intensive functions. In California, a typical operation to seal transverse cracks in AC pavement involves a crew of eight individuals that can seal between one and two lane miles per day. The associated costs are approximately $1800 per mile with 66% attributed to labor, 22% to equipment and 12% to materials. Furthermore, the procedure is not standardized and there is a large distribution in the quality of the resultant seal. In addition, while crack sealing/filling, the work team is exposed to danger from moving traffic in adjacent lanes.

The crack sealing/filling operation is an ideal candidate for the infusion of advanced technologies to automate the process. Automated crack sealing/filling machinery has the potential to:

- Minimize the exposure of workers to the dangers associated with working on a major highway.
- Increase the speed of the operation.
- Improve the quality and consistency of the resultant seal.

Increasing the speed of the operation will in turn reduce the accompanying traffic congestion since lane closure times will decrease. The combination of the increased speed and the higher quality seal will prove to be extremely cost effective and reduce the frequency of major highway rehabilitations. To have the greatest impact, such machinery should satisfactorily perform the following functions automatically:

- Sense the occurrence and location of cracks in pavement.
- Adequately prepare the pavement surface.
- Prepare and dispense the sealant/filler.
- Form the sealer/filler into the desired configuration.
- Finish the sealer/filler.

Additionally, the machinery will have many other more detailed overall functional specifications related to safety, cost, reliability, etc.

This paper discusses progress of the SHRP's H-107A Project, "Fabrication and Testing of Maintenance Equipment Used for Pavement Surface Repairs - Crack Sealing/Filling." The participants of this project include: University of California-Davis (prime contractor), California Department of Transportation, Bechtel Corporation, ERES Consultants, Inc., and Odetics.

MACHINE DEVELOPMENT PLAN

The development plan for the automated crack sealing machinery involves several critical aspects. The machine is divided into two main machine subsystems, one to address longitudinal cracks operating off the side of the vehicle, and the other to address general cracking, such as transverse cracks, off the rear of the vehicle. Each of these machine primary subsystems use identical components minimizing the parts inventory of the machinery. Also, each of the component subsystems is able to operate as a stand alone unit, which provides for the maximum flexibility in machinery configuration and allows for each user to outfit his machine according to his personal crack sealing method. This will provide for the largest possible market. Figure 1 is a computer graphics rendition of the machine concept and this figure clearly shows the two main machine subsystems. Graphics animation of the concept vehicle has been an important tool in the development process.

To expedite machine development, component feasibility testing has been incorporated with first generation component testing whenever possible leading to the rapid development of application specific second generation components. Finally, the use of commercially available components whenever possible has been emphasized to maximize reliability and accelerate development.

MACHINE ARCHITECTURE

The overall machinery system architecture includes seven primary systems, Vision Sensing System (VSS), Local Sensing System (LSS), Applicator and Peripherals System (APS), Robot Positioning System (RPS), Vehicle Orientation and Control System (VOC), Path Planning Module, and Integration and Control Unit (ICU). Of course, these systems would in turn be mounted or towed by a support vehicle. The Vision Sensing System will be primarily responsible for locating and describing roadway cracks and joints. The Local Sensing System is a laser range finding based system to verify the presence of cracks and to provide fine position information. The Applicator Assembly and Peripherals include the hardware necessary to mix, heat, dispense, shape and finish sealant/filler, and to prepare the pavement including reservoir creation. This system may be comprised of any number of dispensers, valves, cutting tools, heaters, air compressors, etc. The Robot Positioning System will include the hardware necessary to move the applicator assembly end effectors in such a manner that they follow the required path. The required path is determined by the Path Planning Module based on the information provided by the VSS and the LSS. Physically, the Path Planning Module is software housed within the ICU. The Vehicle Orientation and Control System monitors and controls the vehicle position and speed, and it is necessary since the VSS is housed at the front of the vehicle and the RPS and APS operate at the rear of the vehicle. Furthermore, the entire crack sealing operation will ultimately be performed as the machine moves continuously down the road. The Integration and

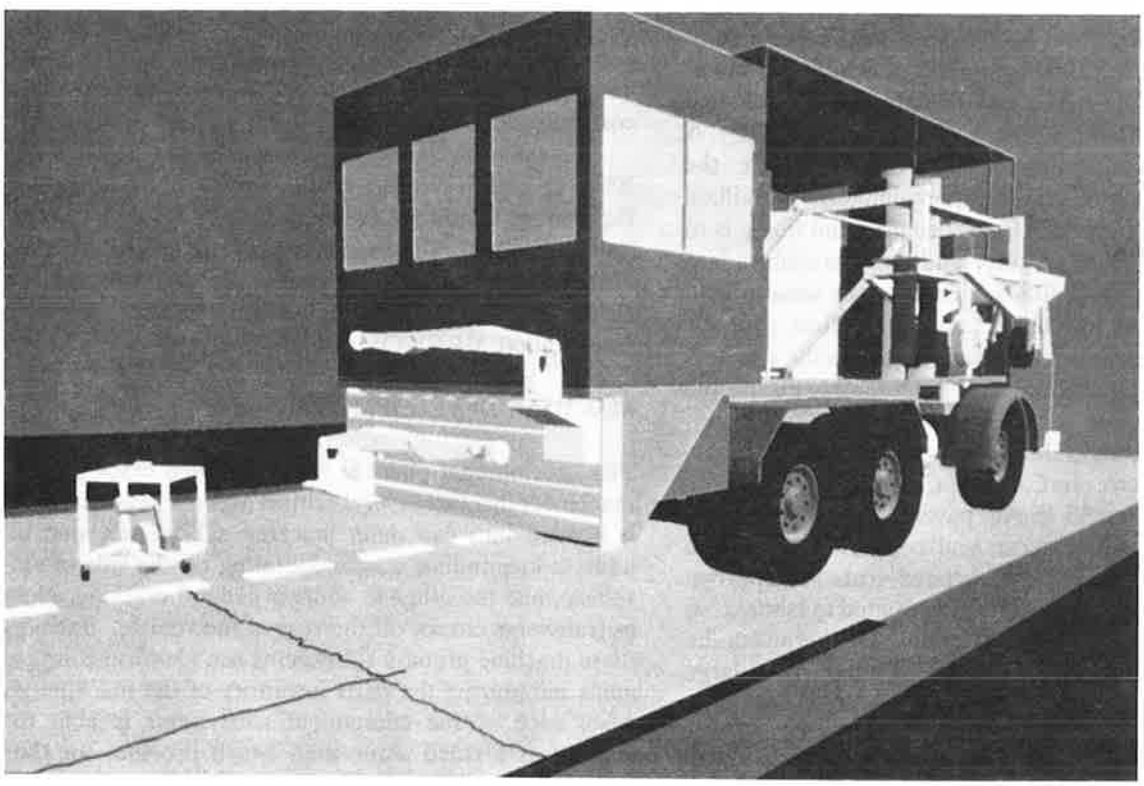


Figure 1 Computer generated pavement crack and joint sealing machine.

Control Unit will coordinate the Crack Sensing, Applicator Assembly and Peripherals, Vehicle Orientation and Control, and Positioning Systems. After the Path Planning Module transforms the information from the Sensing System into a desired path for the applicator assembly, the ICU will then control the motion of the applicator through the Positioning System as well as controlling the individual functions of the Applicator System. Additionally, the ICU will monitor all of the peripherals to ensure proper sealant/filler supply, sealant/filler temperature, heat supply, etc. Figure 2 shows the functional architecture of the machine in terms of computational integration. A brief description and development progress of each of these component systems follows.

Integration and Control Unit

The development of an Automated Crack Sealing machine (ACSM) includes the integration of a variety of sensing, command and actuating systems, many of which will synchronously perform tasks in real-time. A control architecture has been developed to assure that these systems act in a coordinated manner to achieve the overall goal of sealing pavement cracks at an acceptable performance level. The choice of the control architecture for a particular product can have a profound effect on the development as well as the commercialization of that product.

The Integration and Control Unit oversees the entire operation and coordinates the activities of the other subsystems. The information forwarded from the Crack Sensing System will be translated into a planned path for the Applicator and Peripherals System components (crack/joint preparation equipment, etc.). Thus, the Integration and Control System will include the necessary algorithms to plan a crack/joint sealing path. This path corresponds to the relative positioning of the Applicator System. If multiple applicators are employed, the Integration and Control System will need first to allocate cracks to the individual applicators and will do so in a manner to maximize speed and avoid interference. This system will keep account of the actual position of the total machine and its components by interacting with sensors on the Positioning System. It will additionally monitor the Applicator Assembly and Peripherals to ensure adequate volume and temperature of sealant/filler, air, etc. Following the planning of the

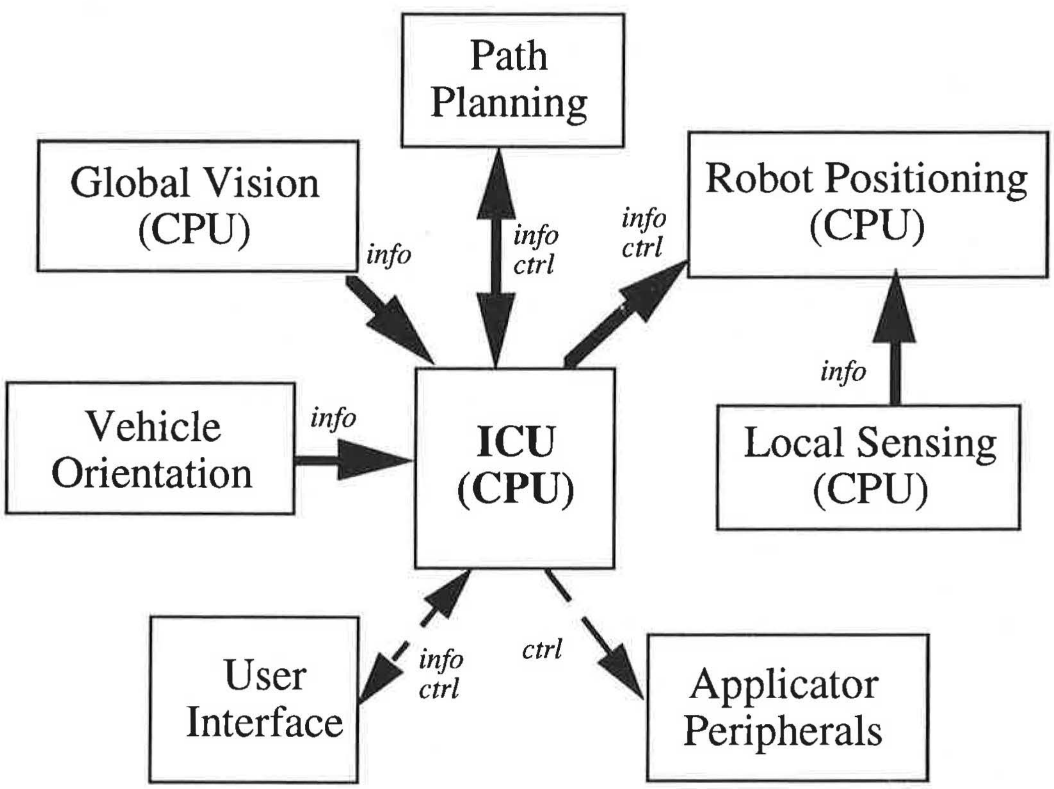


Figure 2 Machine Functional Architecture.

appropriate path(s), the Integration and Control System will control the motion of the applicator(s) and the individual applicator functions.

In review of the machine requirements, the ICU must meet the following criteria:

- fast and efficient computation,
- able to recognize and process prioritized interrupts
- process concurrent information rapidly (multi-tasking),
- retain sufficient spare capacity and flexibility to expand,
- support multiple processors, and
- expandable backplane.

In addition to these necessary requirements, other development requirements were recommended as follows:

- modular in both hardware and software design
- application software should be developed in a user-friendly environment that is common to many programmers,
- system software should be ROMable to enable an embedded application,
- vehicle mounted ICU needs to be rugged to operate in a hostile environment, and
- compatible with other CalTrans/UCD in-house development efforts and expertise.

Considering the responsibilities of task monitoring as well as the development requirements, a VME system bus architecture utilizing an OS-9 real-time operating system was selected as the most desirable based on all considerations and requirements. The VME bus provides the highest bus transfer rate, is rugged enough to perform in the maintenance vehicle environment and is a flexible system. The VME bus provides the flexibility, compatibility, modularity and multi-processing necessary for the efficient operation of the ACSM. OS-9 was recommended as the operating system for the VME bus because it is increasingly accepted as a standard and complies with the requirement to be compatible with other ACSM subsystems and other CalTrans and UC-Davis automated highway maintenance projects.

The VME computer system utilized is a commercially available system. Thus far, the basic control architecture has been implemented on this system. Communications have been established to several other subsystems and these have been demonstrated in real time. The preliminary user (operator) interface has also been implemented. That is, operator communication with the ACSM will take place through a computer terminal and the display screens have been designed and demonstrated providing a view of the types of information that will be passed on to the operator.

Vision Sensing System

The purpose of the Vision Sensing System (VSS) is to locate pavement crack positions using machine vision. The VSS processes information from a gray scale image of the top view of a section of pavement, approximately 12 feet wide (one lane width). Acquisition of the image is coordinated with the rotation of the ACSM wheels to maintain a proper aspect ratio of the pavement image. Hence, the image is created by the forward movement of the vehicle. As the computer acquires sufficient blocks of image data, a 10 inch long by 12 foot wide block of video data is built in increments of two inch square tiles. For each of the tiles the determination is made whether a crack exists, and if so, in which of eight directions is it headed. This data is immediately transferred to a remote storage area for path planning and updating from the ICU and Vehicle Orientation and Control System (VOC) as the vehicle continues to move forward.

The VSS has been constructed and preliminary testing has taken place with the use of the Odetics Mobile Imaging Laboratory. This laboratory is a truck with enclosed bed that contains adequate power, air conditioning, monitors, tape recorders, and other electronic equipment and mountings for vision system testing, and in particular, it contains Datacube vision processing equipment and support computers compatible with our vision system hardware. The VSS consists of two cameras, lighting, an encoder, and system unit that encompasses image processing hardware and crack detection algorithms. The lighting system has been designed to ensure operation both during the daylight and nighttime hours thus providing maximum usage of the ACSM. The preliminary testing has shown the ability of the VSS to locate cracks in both AC and PCC pavements as small as 0.2 inches.

Vehicle Orientation and Control System

The Vehicle Orientation and Control (VOC) system tracks the position of cracks on the road surface with respect to a fixed point (e.g. the robot base) located on the truck. This system is required so the position of road cracks identified by the Vision Sensing System (VSS) at the front of the crack sealing truck can be tracked continuously as the truck moves forward to position the cracks within the work space of the robot arms at the rear of the truck. At that point, the crack position data will be sent to the controllers on the robot arms (RPS) via the ICU. The robot controllers will then send signals to position the end effectors of the robot arms over the cracks. Once positioned, the end effectors will rout, clean, heat, and finally seal the cracks. It is our intent that ultimately the entire process of identifying the cracks, tracking their positions, positioning the robot end effectors, and performing the crack repair operation will be done in a continuous fashion with the truck moving ahead at a slow forward speed.

The entire VOC system will use digital communication. Two optical, rotary, incremental encoders will each be mounted on separate "fifth wheel" assemblies. The fifth wheel assemblies will be mounted on either side of the truck outside the rear wheels and between the two rear axles of the truck so the center line of the encoders passes through the center of rotation of the truck. The fifth wheel assemblies will continuously monitor the change in position of each side of the truck. From position data obtained from the encoders, the translation of the truck (laterally with respect to the road surface) and rotation of the truck (yaw - about a vertical axis with respect to the road surface) can be continuously calculated.

An on-board computer also will be a part of the VOC. This computer will serve several functions. In general, crack position data will be sent to the VOC computer from the VSS and truck position data will gathered from the encoders on the fifth wheels. Calculations of truck position and orientation and crack position (with respect to the truck) will be performed by the VOC computer, and this information will be shared with the ICU.

The VOC has been exercised on a movable cart to simulate motion on the actual ACSM. Based on preliminary testing minor modifications are being performed and the fifth wheel assemblies are in the manufacturing phase.

Local Sensing System

The purpose of the Local Sensing System is to locate crack position and measure crack width to a degree of precision such that the crack preparation, sealant application and shaping of the seal can be performed in an automated fashion.

On the general crack sealing machine, the LSS will work with the VSS to confirm the presence of a crack within a given area. The VSS will locate the approximate position of a possible crack using a video camera. This camera uses a line scan charged coupled device (CCD) as its sensing element. As the vehicle moves, lines across the lane width will be gathered to form an area view of the road surface. Through measuring the intensity of gray levels that the camera senses, it is possible to determine the position of possible cracks. However, since the line scan camera only has two-dimensional measuring capabilities, it may mistake an oil spot, shadow, or previously filled crack for an actual crack. The purpose of the LSS on the general machine is to scan the area near the potential crack location identified by the VSS to confirm or reject the presence of a crack. Furthermore, there are inherent inaccuracies in the VSS crack identification algorithm that gives it a resolution of approximately ± 1 inch. There are also errors associated with the motion of the vehicle that will result in errors in the crack location identified by the VSS. Therefore, the LSS also will provide more precise position information to the general Robot Positioning System (RPS). Local sensing will provide range information that can accurately sense the presence and position of a crack. However, local sensing alone would not be adequate because the local sensor requires a planned path to scan for random cracks. Because of the operating speed of the vehicle, the update rate and field of view of the local sensor are not adequate to track random cracks without prior knowledge of crack direction.

On the longitudinal crack sealing machine, the local sensor will provide all sensing information to the longitudinal RPS. Because the longitudinal cracks do not randomly vary in direction, it is possible to design a sensing system in which the local sensing system provides an error feedback signal to the longitudinal RPS. The start of the crack must initially be placed within the local sensor field of view, and then through real time controls and feedback provided by the local sensor, it will be possible for the longitudinal RPS to follow the longitudinal crack.

A variety of sensors technologies have been researched to select a sensing system that best meets the sensing requirements. The Local Sensing System that has been selected is the most cost effective, off-the-shelf component that meets all the requirements. The system selected is a laser vision sensor which measures range information using triangulation. Using triangulation, distance measurements are determined by transmitting a laser light source, then focusing the diffusely reflected light source on a photosensitive device. This method of detection is reliable and is commercially available and widely used for seam detection during automated welding.

Sensing systems based on triangulation are impervious to color variations. Therefore, a laser range finding sensor will work well on all pavements. Also, laser sensors are not sensitive to a dusty environment. Furthermore, laser triangulation is insensitive to lighting conditions because the sensor provides its own lighting via the laser. Overall, laser triangulation is a reliable technique for extracting three-dimensional surface characteristics.

To achieve optimal field of view and update rate from the sensor, a laser vision system using structured light was chosen. Laser vision systems based on structured light offer reliability, design simplicity, compactness, while maintaining cost effectiveness. Structured light extracts a three dimensional surface profile by projecting a laser pattern in a plane perpendicular to the surface being measures. The line of light is then observed by a CCD camera at an angle allowing the surface features to be found.

A commercially available sensor has been purchased which is simple to use and rugged in harsh environments. The sensor has a built-in heat exchanger for cooling and a cleaning mechanism that prevents dust from settling on the lens that would distort the image. These attributes are attractive given the harsh environment associated with automated crack sealing. The sensor itself is a small package weighing 9 ounces and measuring 4 by 3 by 1.6 inches. This package contains a laser light source, a CCD camera, and appropriate optics. The sensor will be mounted to the robot with a provided precision machined camera bracket. A vibration isolator will be placed between this bracket and the robot arm to protect the sensor from harsh vibrations and to prevent the image from being distorted. This system has been tested for performance on actual road surfaces, and additionally, it has been interfaced with a laboratory robot system to establish its adequacy for the ACSM.

Robot Positioning System

Our development approach has led to the development of two robot positioning system components, one for addressing longitudinal cracks off the side of the vehicle and one to address cracks off the rear of the vehicle. These systems are denoted as the longitudinal positioning system and the general positioning system, respectively.

For the general positioning system, a GMF A-510 SCARA manipulator and Karel controller have been purchased. The purpose of the manipulator is to guide process carts over pavement cracks as part of the general crack sealing machine. The GMF A-510 is a SCARA type four degree-of-freedom manipulator. Manipulators such as these are commonly used for assembly operations, food packing, and palletizing. Each joint is driven by a servo motor and the relative position of the joint is recorded by encoders. The servo motors and encoders are interfaced with the Karel controller. The A-510 manipulator was selected from a field of commercial manipulators on the basis of workspace, payload, and controllability.

The A-510 manipulator will be inverted and mounted on a linear slide on the back of the crack sealing truck. Figure 3 is a drawing of the manipulator-slide system as it will be mounted on the support vehicle. The Karel controller is a fully integrated robot motion controller that will be responsible for all motion of the manipulator. The controller will receive input from the LSS and the ICU that will provide it with necessary information to control the manipulator which in turn guides the process carts over cracks in the pavement. The Karel controller is able to use information from the encoders to move the end effector to locations within the workspace of manipulator. Pre-programmed information on the manipulator kinematics allows the controller to move the manipulator to points in Cartesian space about the base of the manipulator.

The manipulator has already been mounted on a custom built, servo controlled linear slide that is also integrated to the Karel controller. The slide has an overall width of 8 feet to fit on the back of the crack sealing truck, and it allows 2.5 feet of horizontal travel. The addition of the linear slide increases the reachable workspace of the manipulator and enhances its dexterity particularly near the edge of the workspace. A normal SCARA configuration manipulator cannot move along a given path within its workspace. In addition to extending the workspace, the addition of the linear slide provides a redundant degree of freedom which will allow the manipulator to move in any direction and along any path (e.g. following a crack) within its workspace. The slide-mounted A-510 and the Karel controller have been connected to a support structure within the laboratory for development purposes. As part of the preliminary testing so far, the LSS has been integrated and the entire system exercised. Additionally, path information has been successfully passed from the ICU to this system, and corresponding motion resulted.

The longitudinal RPS is the subsystem that carries the local sensor, the router, the vacuum and heater/blower ducts and the sealant applicator unit during operations on longitudinal pavement cracks running parallel to the roadway. The longitudinal

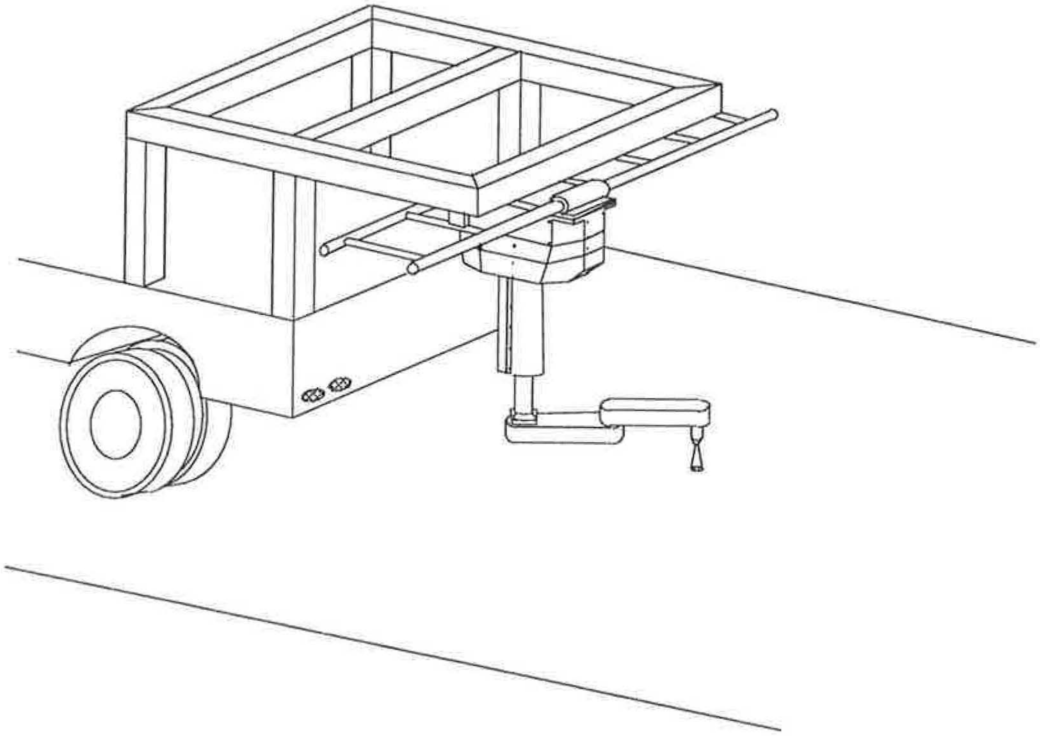


Figure 3 Drawing of the manipulator-slide system.

positioning system has two major component systems, the mechanical linkage structure that includes the end-effector cart, linear slide table, and the connecting links, and the actuator and control system. A commercially available prepackaged electro-hydraulic linear drive was selected for the actuator and control system consistent with our development philosophy.

The cart is attached to the side of the road maintenance vehicle with a mechanical linkage that allows the cart to move laterally a distance representative of crack geometry and driver capabilities as the vehicle is driven alongside the crack. The lateral movement is controlled automatically to correct for the relative position of the vehicle to the crack. The linkage also allows the cart to be retracted from the road when not in operation. Figure 4 shows the motion capabilities of the longitudinal positioning system. Figures 5 and 6 show the component configuration on the longitudinal RPS with and without the routing capability, respectively.

The following design features have been incorporated into the longitudinal RPS system:

- The actuator control system is simple. To accommodate this, the linkage allows the cart to translate laterally with the movement of the actuator.
- The linkage design is such that motion of the cart due to the changes in elevation and angle of the road surface result in the least possible lateral translation - which are compensated for by the actuator.
- Stowage is simple.
- A cart length of 5 feet is provided to allow installation of all APS components. Lateral movement of the cart is limited to 12 inches total, representative of operator's driving abilities.
- Designed for ease of application to any size support vehicle. The particular prototype built is dimensioned around the 40 inch high bed of the test vehicle made available to the project by Caltrans.

The first generation longitudinal positioning system, which does not include the automated positioning, has been delivered to Caltrans for on-road testing and debugging of the longitudinal RPS and the sealant applicator component. This testing will provide invaluable information on worker acceptance, quality of seal, ease in assembly on existing vehicles, and numerous other aspects all essential for commercialization.

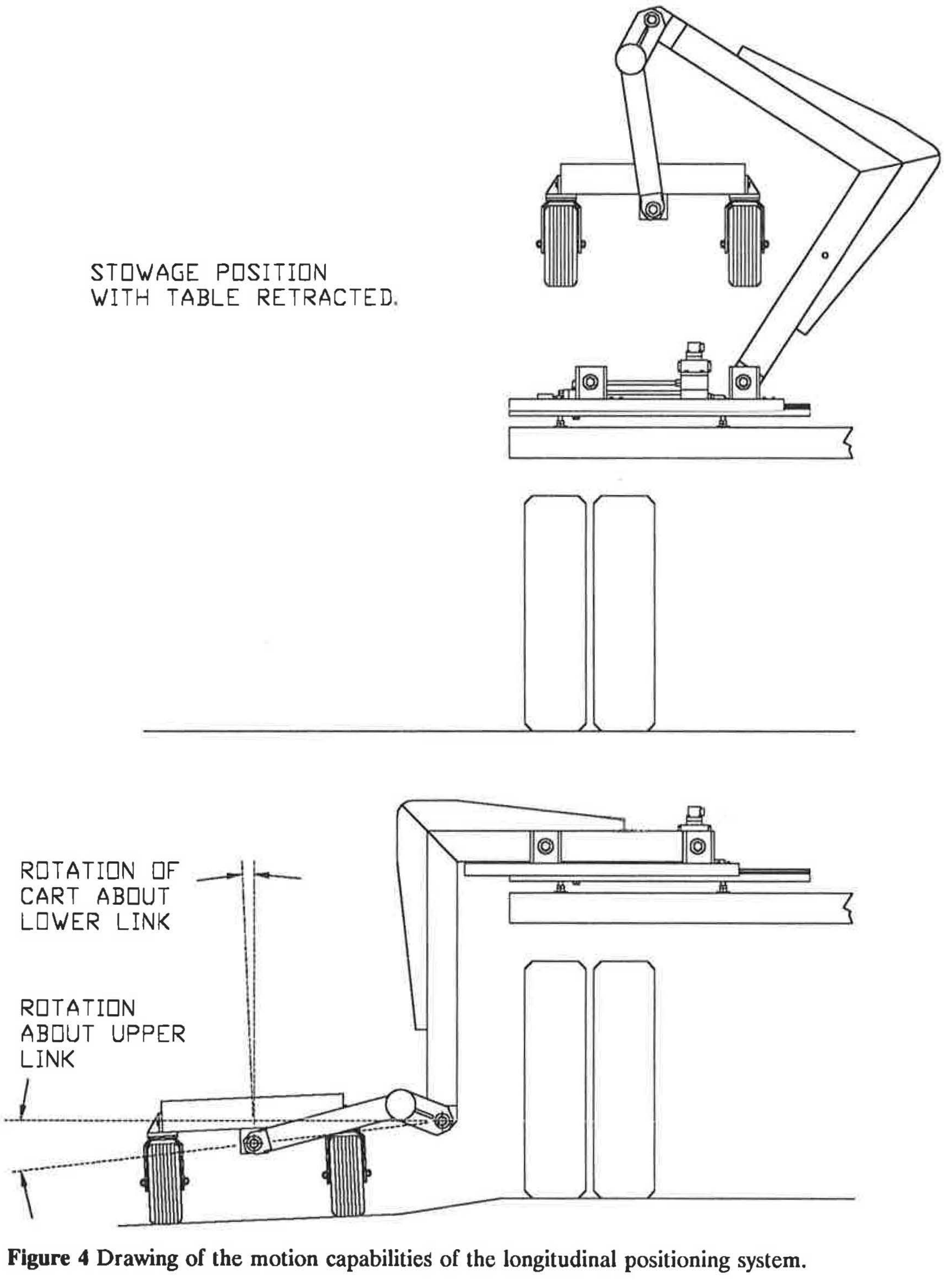


Figure 4 Drawing of the motion capabilities of the longitudinal positioning system.

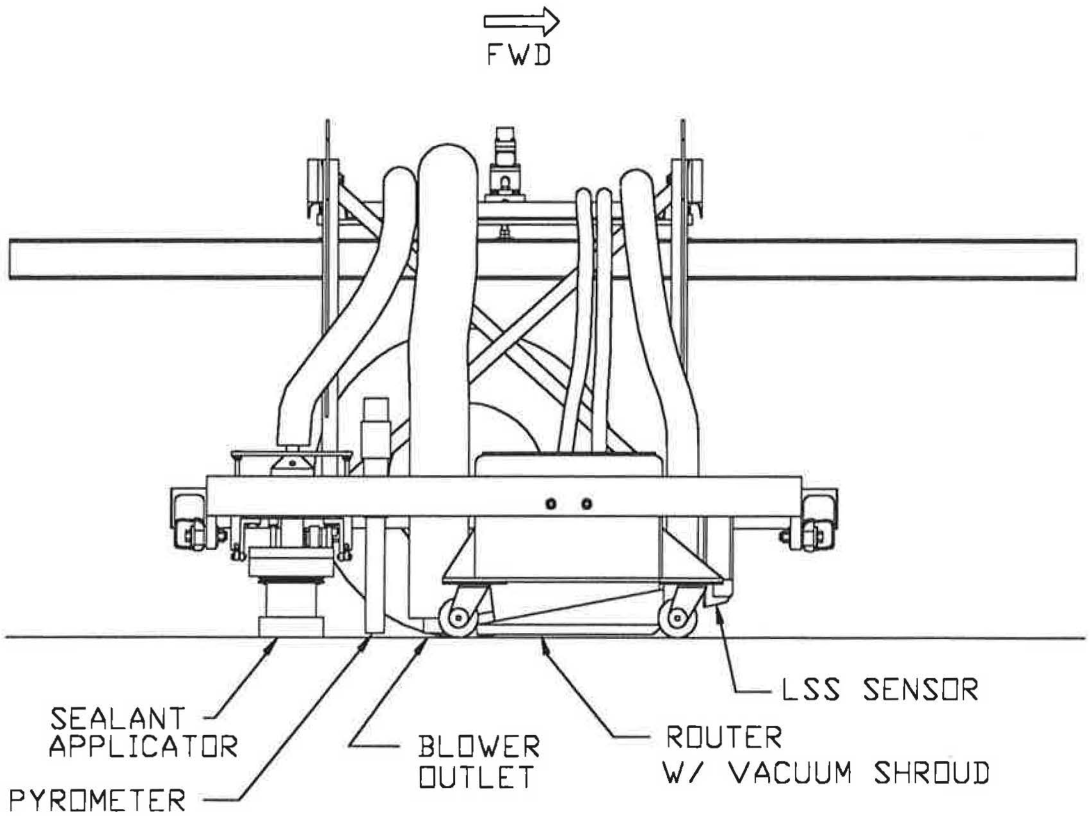


Figure 5 Drawing of the component configuration on the longitudinal robot positioning system with the router.

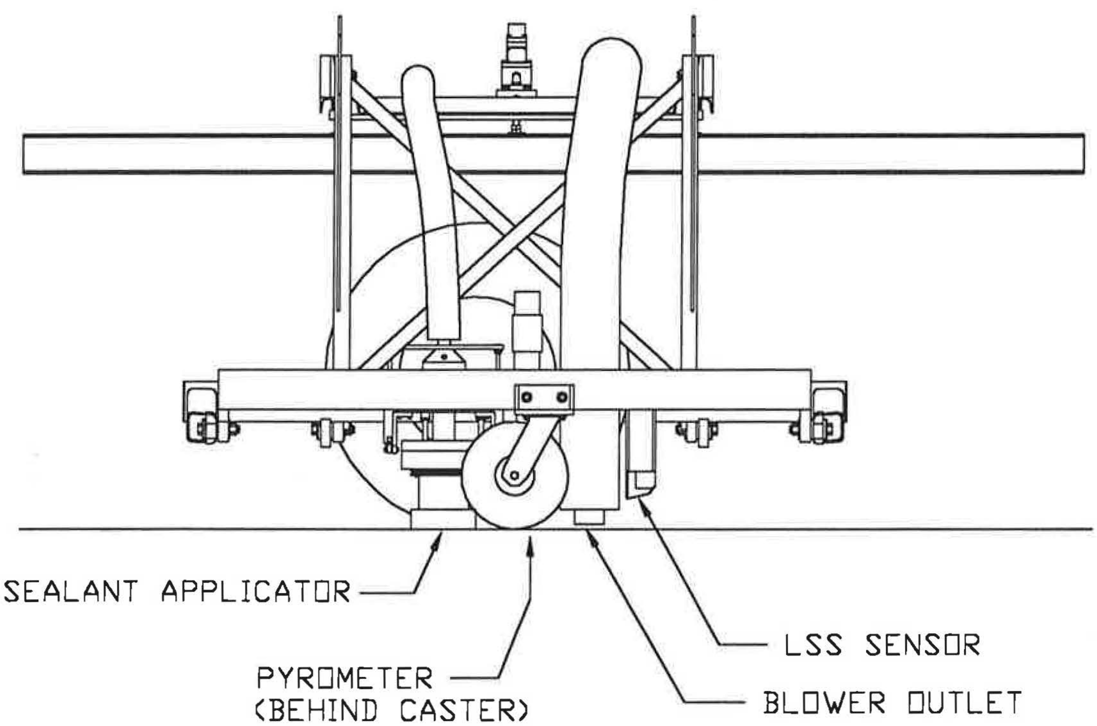


Figure 6 Drawing of the component configuration on the longitudinal robot positioning system without the router.

Applicator Assembly and Peripherals System

The key to sealed/filled crack/joint longevity is directly attributable to proper cavity preparation. Additionally, for most hot applied sealants/fillers, a uniform surface heating before application is desirable. While there are significant differences between the practices of the various states, for the widest possible applicability, an automated machine also must allow for pavement routing. The Applicator Assembly and Peripherals System prepare the crack/joint and applies and finishes the sealant.

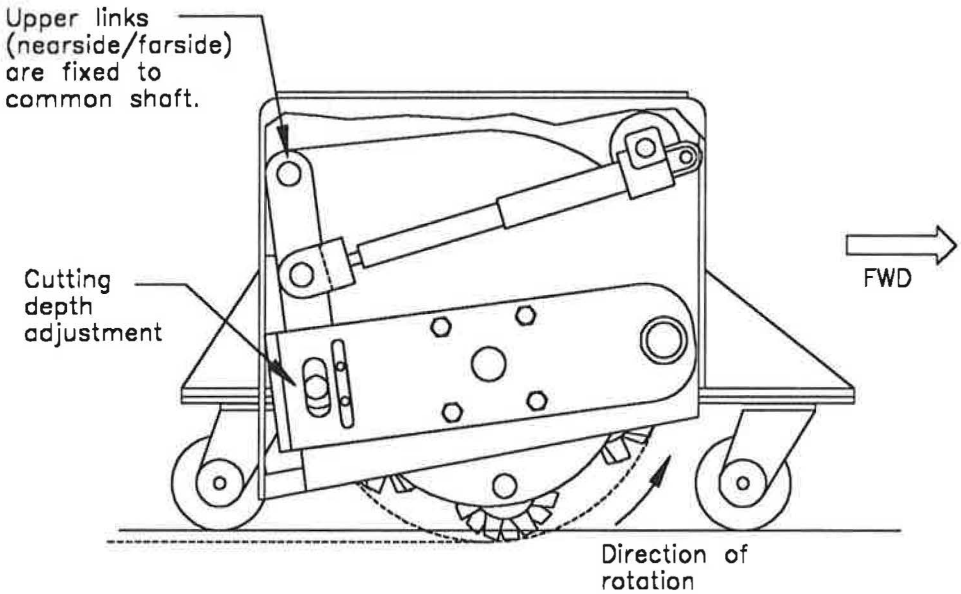
Recent studies(*1*) have shown that the ideal method for crack preparation should include the use of a two phase hot air system. The primary phase of this system should include a source of high temperature and high velocity compressed air to remove entrapped aggregate/ vegetation and moisture. The second phase of the heating system should be used to warm, to approximately 280°F (based on recent studies at Caltrans), the surrounding horizontal crack margins to ensure a highly adherent bond between the surface and the sealant material. Once the crack is cleaned, dried and heated, a suitable sealant can be applied. The desired patch configuration requires moderate penetration of sealant material into the vertical crack surface, and sealant penetration can be sharply increased as the temperature differential between the surface and the sealant material is minimized. Thus, we have been developing routing, heating/cleaning/debris removal, and dispensing components for the ACSM, and we will now address each of these components.

The router is used to prepare cracks by cutting a channel along the crack in a profile that allows for increased penetration and adhesion of the sealant. The router was developed to accommodate the unique requirements imposed by the automated crack sealing machine. The design uses an existing impact router cutting wheel installed in a configuration that will follow random cracks with the general purpose RPS or the nearly linear cracks with the longitudinal RPS. It is hydraulically powered which allows it to be operated with a remote power supply. As a result, its size and weight are minimized to best accommodate its use with the RPS systems. In addition, the design allows for cutting at the increased speeds necessary for the automated crack sealing applications. The impact cutter design allows for variations in cutting depth and width that can be adjusted by placing the individual cutting wheels in various configurations. Adding cutters and increasing the rotational speed of the cutting wheel assembly also allows for operation at higher road speeds. The router component is a modular unit that will operate in both systems with minor modifications.

The routing component consists of a commercial impact cutting wheel mounted in a frame supported on casters. The weight of the router unit is supported entirely by its wheels and the wheeled frame is designed to resist all forces that act to upset the cart during operation including forces from the RPS to which it is attached. The cutting wheel holds six rows of cutters and is designed to run at 2000 RPM. The cutters have a diameter of 4.75 inches and the total effective cutting diameter of the wheel is 15 inches. The maximum cutting width of this wheel is 2.25 inches, limited by its cutting wheel design. A linear drive is incorporated to extend and retract the cutting wheel. A debris shroud from the debris removal system will be attached to the bottom of the router shroud. It includes a deflector plate forward of the cutting wheel that directs the debris to the vertical tube attached to the vacuum line of the debris removal system.

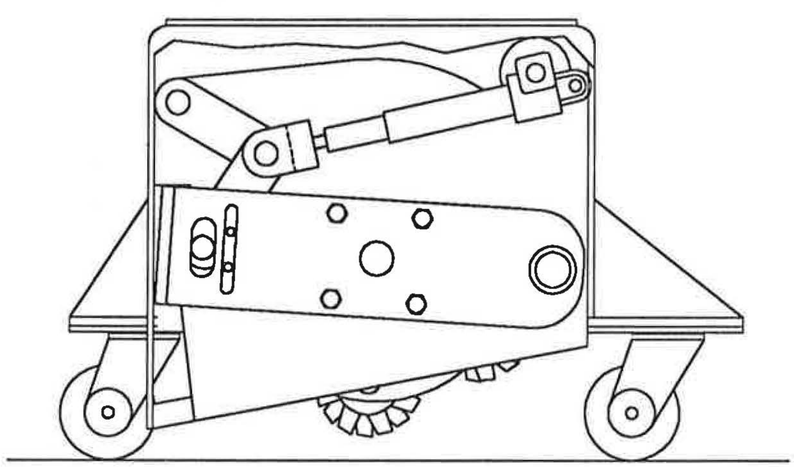
The basic principles of impact router operation have been verified on a manually operated commercial routing unit. The operator, while walking backwards and pulling the machine, guides the unit by observing the cutting wheel as it follows the crack. Debris is thrown in the direction away from the operator. This mode of cutting runs the cutter wheel in a "down-milling" cut direction. Testing showed that the router tended to pull itself up out of the road bed when operated at higher surface speeds. By pushing the router, which results in a conventional "up-milling" cut, the operation of the router is considerably smoother. Greater force is required push the unit since the resulting cutting force acts in the direction opposite the direction of travel. However, a significant advantage is that the routing machine does not pull itself out of the roadway when "up-milling." Test results determined that operating the router in the conventional "up-milling" mode was the most efficient and would be used for the APS router component. This option is not possible with the manually guided machine since the debris would be thrown toward the operator. The router has been built and tested on actual pavement, and it is ready for installation on the final prototype machinery. Figure 7 is a schematic of the router.

The heating, cleaning and debris removal (HCD) subsystem includes: a debris separator, a 5 PSI, 400 SCFM hydraulically powered centrifugal blower, a 692,000 BTU/hr Thermal Blast Heater, and an infrared pyrometer to measure crack temperature and thereby modulate fuel flow to the burner. Overseeing safe



Router cutting wheel extended for cutting. Cutting depth shown set at mid-range.

(View is cutaway of wheel support frame and does not show dust collection shroud.)



Router cutting wheel retracted.

(View is cutaway of wheel support frame and does not show dust collection shroud.)

Figure 7 Schematic drawing of the router.

operation of the burner is a standard flame safeguard control panel that features additional control panel functions for diverter valve actuation (to ensure safe idle operation), CLEAN ONLY operation (no heat), and a PID controller to interface with the pyrometer. The debris removal portion of this system consists of a debris shroud mounted to the router casing, the separator unit and waste container located on the truck bed, and flexible hoses. The blower provides vacuum air to the debris shroud and separator unit and the waste container houses all collected debris for later disposal. Both the blower and burner units are to be located on the truck in a location that minimizes pressure and heat losses through minimal bending and plumbing distance. Proper insulation will protect subsystems and operators from danger. Hydraulic power to the blower is provided by the central hydraulic system. The pyrometer is located aft of the burner exhaust nozzle on the longitudinal sealant cart and between the sealant applicator and heater nozzle exit on the general process cart. This system has been designed based on detailed heat transfer analysis, and extensive testing of existing blowing and heating units. Again, this system is comprised of commercially available components.

The sealant applicator unit constitutes a significant advancement in crack sealing technology. It was designed to deliver hot thermoplastic sealant at an increased velocity over current crack sealing techniques, as well as shape the material to produce a variety of sealant finish configurations. A significant advantage this unit possesses over other sealing methods is that it uses a small amount of pressure to force sealant into the crack. The sealant flow rate is automatically adjusted according to the cross-sectional area of the crack. The unit is designed for operation in both positioning systems. The sealant applicator is being tested by Caltrans in the longitudinal RPS. Figure 8 is a photograph of the sealant applicator.

Path Planning Module

Based on the importance of the path planning of the robot positioning systems (i.e., how identified cracks will be addressed by the RPS), the Path Planning Module, which actually is software internal to the ICU, is considered an independent subsystem. The path planning routine must convert the processed vision data from the VSS into a format that is usable by the RPS. The essential tasks are to find connected components, and plan a path for the manipulator for the individual crack segments in a frame. Due to constraints on the VSS hardware and software, there will generally be missing segments on a given crack. One task of path planning is to connect segments together, subject to a minimum separation criterion. The fundamental path planning algorithm includes: converting VSS data into array; growing crack data to connect regions, subject to minimum separation specification; thinning the resulting data using some form of medial axis transformation (MAT), scanning the final array data for connected cracks, and converting to RPS format. The RPS format consists of a list of x,y coordinates, and an associated orientation for the manipulator end-effector. This list will be sent by the ICU over a serial line to the RPS, after it has been transformed using the VOC data. The code for this algorithm is working on a Silicon Graphics workstation, as well as on an IBM PC, and it is able to plan a path for a single crack.

CONCLUSIONS

This paper has discussed progress towards the development of an automated machine for the sealing of cracks in pavement. Such machinery is being developed under the sponsorship of the Strategic Highway Research Program (SHRP H-107A) and the California Department of Transportation Office of New Technology and Research. Significant components of this machine have been and are being tested, the integrated prototype machine will be field tested late in 1992. A machine to address only longitudinal cracks and joints, such as construction joints running along the direction of travel of the highway, is being field tested by Caltrans personnel.

REFERENCE

1. Rossman, R.H., H.G. Tufty, L. Nicholas, "Value Engineer Study-Repair of Transverse Cracking in Asphalt Concrete," FHWA Final report, 1988.

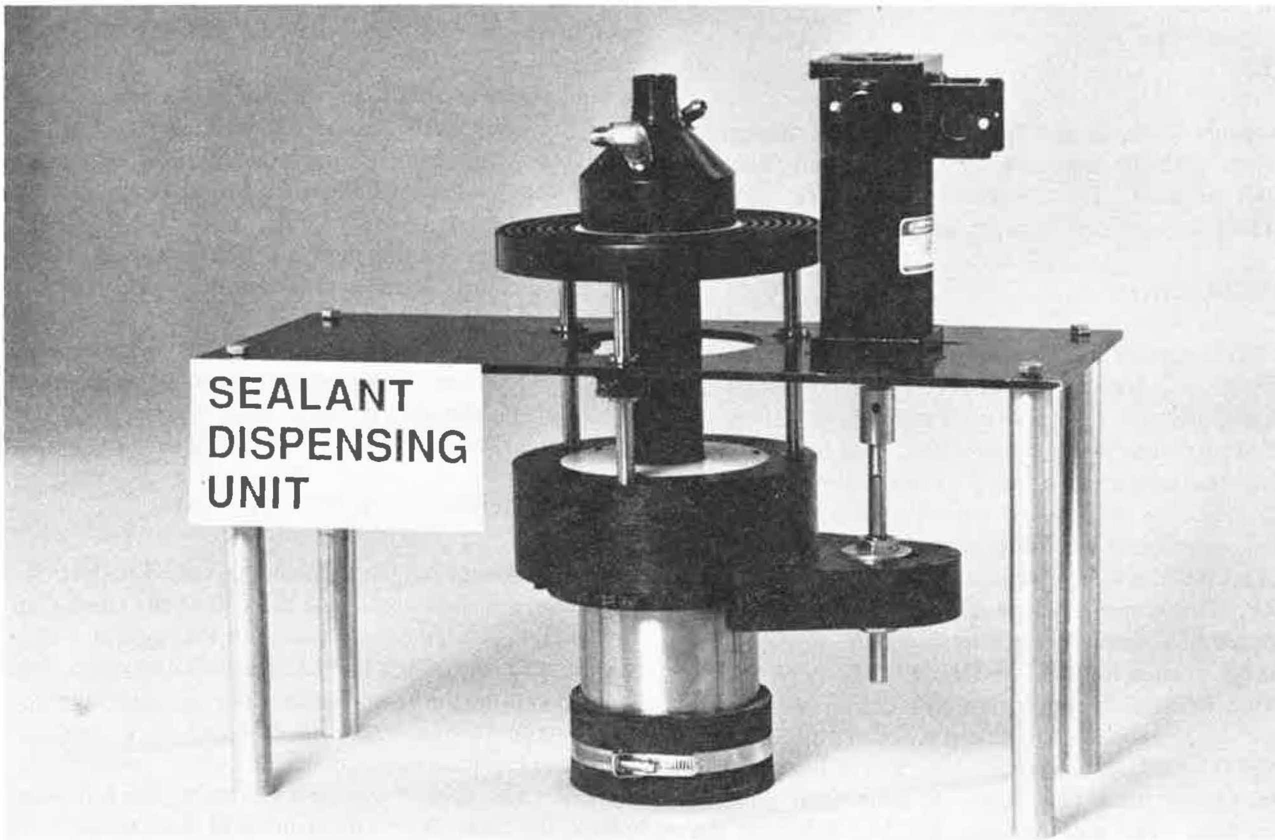


Figure 8 Sealant applicator/dispensing unit.