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Development of the Sealzall Machine - Upgrade to the TTLS (Pavement Crack Sealer)

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16. ABSTRACT

The AHMCT Research Center, together with Caltrans, has been leading a multi-year research effort to develop innovative high production crack sealing equipment, which improves safety while reducing costs. The Sealzall Machine development project is the latest version of a line of successful longitudinal crack sealing machine prototypes developed and deployed with Caltrans on California highways. The program's key technical element has been the application of automation technologies and custom engineering solutions to achieve increased sealing efficiencies and to eliminate the workers' exposure to highway traffic. The preceding Transfer Tank Longitudinal Sealer (TTLS) development project produced a prototype high production longitudinal sealing application vehicle and a large capacity transfer kettle trailer designed to efficiently resupply and support high production highway sealing operations. Defective commercial sealant melting equipment had rendered the TTLS equipment effectively unusable for general deployment. In addition to replacing deficient components, Caltrans requested inclusion of additional features to further enhance functionality. The most significant upgrade was to add in-lane sealing capabilities. An electrically heated sealant hose and application wand assembly was developed on the front of the application machine to support manual in-lane crack sealing capabilities. The rebuilt TTLS application vehicle was then renamed Sealzall to reflect the expanded sealing capabilities. The Sealzall machine retains the continuous 2-5 mph moving lane closure longitudinal sealing functionally first developed for the TTLS with the additional features of compressed air blast crack cleaning and hot sealant recirculation. The Sealzall will ultimately be turned over to Caltrans for full highway operational deployment.

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Abstract

The AHMCT Research Center, together with Caltrans, has been leading a multi-year research effort to develop innovative high production crack sealing equipment, which improves safety while reducing costs. The Sealzall Machine development project is the latest version of a line of successful longitudinal crack sealing machine prototypes developed and deployed with Caltrans on California highways. The program's key technical element has been the application of automation technologies and custom engineering solutions to achieve increased sealing efficiencies and to eliminate the workers' exposure to highway traffic. The preceding Transfer Tank Longitudinal Sealer (TTLS) development project produced a prototype high production longitudinal sealing application vehicle and a large capacity transfer kettle trailer designed to efficiently resupply and support high production highway sealing operations. Defective commercial sealant melting equipment had rendered the TTLS equipment effectively unusable for general deployment. In addition to replacing deficient components, Caltrans requested inclusion of additional features to further enhance functionality. The most significant upgrade was to add in-lane sealing capabilities. An electrically heated sealant hose and application wand assembly was developed on the front of the application machine to support manual in-lane crack sealing capabilities. The rebuilt TTLS application vehicle was then renamed Sealzall to reflect the expanded sealing capabilities. The Sealzall machine retains the continuous 2-5 mph moving lane closure longitudinal sealing functionally first developed for the TTLS with the additional features of compressed air blast crack cleaning and hot sealant recirculation. The Sealzall will ultimately be turned over to Caltrans for full highway operational deployment.

Executive Summary

The AHMCT Research Center, together with Caltrans, has been leading a multi-year research effort to develop innovative high production crack sealing equipment, which improves safety while reducing costs. The Sealzall Machine development project is the latest version of a line of successful longitudinal crack sealing machine prototypes developed and deployed with Caltrans on California highways. The program's key technical element has been the application of automation technologies and custom engineering solutions to achieve increased sealing efficiencies and to eliminate worker direct highway traffic exposure during operations.

The earlier Transfer Tank Longitudinal Sealer (TTLS) development project produced a prototype high production longitudinal sealing application vehicle and a large capacity transfer kettle trailer designed to efficiently resupply and support high production highway sealing operations. Defective commercial sealant melting equipment had rendered the TTLS equipment effectively unusable for general deployment. The TTLS application machine sealant kettle at a minimum required replacement, and for the rebuilding process Caltrans requested inclusion of additional features to further enhance functionality.

The most significant upgrade was to add in-lane sealing capabilities to the traditionally longitudinal only sealing class of machines. An electrically heated sealant hose and application wand assembly was developed on the front of the application machine to support manual in-lane crack sealing capabilities. The rebuilt TTLS application vehicle was then renamed Sealzall to reflect the expanded sealing capabilities. The Sealzall machine retains the continuous 2-5 mph moving lane closure longitudinal sealing functionally first developed for the TTLS with the additional features of compressed air blast crack cleaning and hot sealant recirculation.

Following a brief initial field-testing and adjustment phase, the Sealzall will be turned over to Caltrans for full highway operational deployment.

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Disclaimer

The research reported herein was performed as part of the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center, within the Department of Mechanical and Aerospace Engineering at the University of California, Davis and the Division of Research and Innovation at the California Department of Transportation. It is evolutionary and voluntary. It is a cooperative venture of local, state and federal governments and universities.

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Chapter 1. Background

1.1. Automated Crack Sealing

The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center and the California Department of Transportation (Caltrans) have been leading an ongoing research effort to develop innovative automated crack sealing equipment for over fifteen years. Several machines have been developed as research demonstration projects and one was successfully deployed and incorporated into a Caltrans Maintenance operation in Districts 6 and 11 as shown in Figure 1.

Figure 1. LCSM2 Sealing in District 6

Pavement cracks as a whole are typically separated into two classifications. The cracks, or joints that run in a longitudinal direction along the edges of the lane are considered to be longitudinal cracks and the remaining traverse cracks, or joints in the lane are referred to as in-lane cracks. The distinction is very important when considering the development and application of automated crack sealing equipment.

Various research studies have presented in detail the inherent differences between pavement cracks and highlighted their unique attributes. As related to automated crack sealing, the distinction dictates the difference between a continuous longitudinal sealing operation and a stationary in-lane sealing operation.

Many years ago the AHMCT Research Center determined that the most efficient strategy is to develop two separate machines as opposed to the more intuitive single platform approach. Obviously a continuously moving operation cannot share a platform with a stationary operation without reducing the efficiency of the moving operation. The separate platform approach is also beneficial for enhancing safety, reducing traffic impact, improving access and increasing production capabilities. Even the generally perceived disadvantage of having to make two trips can actually be considered a net benefit when considering traffic impact, access issues and production capabilities.

The AHMCT Research Center has built functional prototypes for both the longitudinal and in-lane versions of the automated crack sealing machines, which were designed to eliminate direct worker highway traffic exposure during sealing operations and increase sealing production rates. This report focuses on the current research and development activities as related to the longitudinal sealing equipment program only.

The AHMCT Research Center together with the Caltrans Divisions of Maintenance, Equipment and Research has been collaborating for many years on the development and deployment of a series of automated Longitudinal Crack Sealing Machines (LCSM). This equipment has been successfully deployed through several different Caltrans maintenance crews across the state to seal cracks cost effectively and with dramatically increased production rates. In order to realize the full potential of LCSM production capabilities, Caltrans supported the

AHMCT Research Center research project to develop a new generation LCSM. The new machine development project would incorporate all the features needed to maximize sealing quality, production and safety discovered through field experiences, combined with the engineering improvements needed to realize the full potential of LCSM production capabilities. Significant increases to the application speed is limited by sealant viscosity and steering issues, but the factor which has consistently limited production in the field is the inability to produce enough hot sealant on the highway to support high speed longitudinal sealing operations.

1.2. Hot Sealant Production

Caltrans consistently experiences a fourfold increase in longitudinal production rate when using the LCSM in their highway sealing operations. LCSM operators typically apply sealant at a flow rate of 1-2 GPM when sealing longitudinal cracks or joints at a continuous vehicle speed of 2-5 mph. Standard sealant melter kettles have between 250 and 400 gallon capacities. The useable volume of sealant in the kettle is approximately 80% of the maximum capacity. In general terms, a standard kettle at best can supply half of a day’s supply of sealant by emptying the kettle, commonly referred to as “stripping” without adding additional sealant.

Caltrans longitudinal sealing operations utilizing the LCSM have consistently confirmed the half-day sealant supply limitation. Therefore, developing the means to at least double the hot sealant supply on the highway remains the main focus of LCSM research. Logically there are two ways to achieve this goal: the required extra sealant can be brought out to the operation cold in boxes and heated on site, or the additional sealant can be heated separately and brought out to the site hot.

Polymer modified asphalt sealant is the common product Caltrans utilizes to seal pavement cracks. The sealant is typically supplied in 9-gallon cardboard boxes and is solid at ambient temperatures and becomes a viscous liquid when heated to a standard application temperature of 375° F (see Figure 2). The thermal properties of the sealant are that of an insulator, resisting heat conduction. Additionally, sealant cannot be subjected to temperatures significantly higher than the application temperature, or the sealant will "coke" meaning it loses its elastic sealing properties and becomes a permanent solid. The combination of these two properties makes sealant blocks difficult to heat quickly which impedes the practice of heating sealant blocks on-site and as needed. Meanwhile, the sealants polymer component limits the time the sealant can be held at application temperature and still retain its useful sealing properties, termed "pot-life", to approximately 8 hours. The pot-life time is cumulative and includes a portion of heat-up and cool down time as well. Having to account for sealant's limited pot-life complicates the method of preheating and maintaining a large amount of hot sealant to resupply the on-site sealing operation.

Figure 2. Typical Sealant Blocks

To achieve maximum sealant melting production, sealant kettle manufacturers recommend to start sealing with a full kettle, then add sealant blocks at a rate equivalent to the sealant output rate, in essence maintaining a full kettle. Submersing the introduced sealant blocks in a pool of hot sealant is the quickest way to melt the blocks, and this effect is kettle independent. As the blocks melt, the kettle heating system must at least replace the heat lost to the pool of sealant in order to maintain application temperature. A legitimate measure of kettle efficiency is the rate at which a kettle can transfer heat into the sealant pool. The kettle heating efficiency determines how quickly sealant blocks can be resupplied without a significant loss of sealant pool temperature commonly referred to as the "Kettle Recovery Rate."

Recovery rates are kettle type specific and determine the kettle production rate when sealant block reheating is involved. Adding blocks too quickly cools the sealant pool temperature below recommended pour temperature, negatively affecting crack seal adhesion and quality. The common practice of adding sealant blocks to keep the kettle full is an effective strategy to achieve a kettle's maximum production rate, as long as the sealant output flow rate is less than the kettle recovery rate. For standard hand-applied crack sealing operations, most commercially available kettles are more than adequate, but as for the LCSM operation, these standard recovery rates prove to be totally inadequate.

Initial LCSM configurations deployed to Caltrans were designed specifically to facilitate the efficient loading of sealant blocks during sealing with the vehicle in motion. The selected sealant kettle provided the best possible recovery rate for a commercially available unit. Regardless, LCSM performance was several times faster than the kettle recovery rate, and sealant pool temperature quickly dropped far below specifications. Low sealant mass temperature reduces seal quality and furthermore retards the sealant block melting rate.

Caltrans operated the LCSM in an area with an unusually ideal climate where sealant adhesion and temperature issues are not as critical and sealing at lower application temperatures was less of a concern. Regardless, as the operation continued with the sealant mass temperature decreasing, eventually the seal flow rate slowed to a point where the sealing process had to be terminated. The kettle at this point was clogged with partially melted blocks, and the remaining warm sealant pool temperature became too viscous to be pumped. A method to solve the partially melted sealant block problem by slicing the sealant blocks into small strips was deployed, but this only exasperated the sealant pool temperature problem and no net production gain was ever achieved. Therefore, the only remaining effective means to increase overall melter recovery rate is to increase the heat transfer rate into the sealant pool itself. Since the heating temperature gradient is limited, a corresponding increase in the size of the heat transfer surfaces is the only solution. This approach would necessitate the design and development of a custom sealant-melting kettle, which introduces a series of additional problems.

When the LCSM research efforts failed to achieve an adequate increase in on-site sealant block melting production, other alternative approaches had to be examined. One approach is to increase the size of the sealant kettle large enough to supply an entire day's production in a single load. Kettles are available with over a thousand-gallon capacity, but Caltrans Maintenance workers unanimously agreed that work zone mobility would be a critical problem. The difficulty of heating the blocks could be avoided altogether by turning to a process where the sealant is mixed hot as it is loaded into the kettle. This process is commonly referred to as "Field Mixing". Field mixing equipment is commercially available and it also drastically reduces sealant cost. However, Caltrans prefers to use boxed sealant, due primarily to material quality control and traceability issues. Research ultimately settled on the approach of utilizing multiple standard kettles together in order to provide the increase in hot sealant supply necessary to meet LCSM production requirements.

1.3. Multiple Kettle Operation

Caltrans built and deployed a duel kettle trailer system with the LCSM2, which was utilized in various districts but was primarily operated in District 11. The design was based on the sealant block melting on-site technique with the added benefit of switching between two kettles to improve sealant melting characteristics. The LCSM2 was successful but was found to be still somewhat lacking in hot sealant production ability.

During the field deployment operations, a Caltrans safety official determined that it was unsafe to have personnel on the truck bed while the vehicle was moving. This ruling prevented Caltrans crews from continuing the procedure of loading sealant blocks into the kettles while the vehicle was sealing, which was the basic operating premise of the machine. From that point on, crews operating the LCSM2 could just dispense the hot sealant capacity until the two onboard kettles were emptied, and this was approximately 480 gallons. Refilling and reheating on-site then became unpractical, since empty kettle recovery is much slower, typically taking several hours.

In an effort to augment the onboard hot sealant capacity, some Caltrans crews incorporated a third trailer-based kettle and conducted on-site hot sealant resupply transferring. This procedure, which is generally referred to as a “Nurse Kettle,” provided 680 gallons of hot sealant capacity to satisfy this specific job requirement. Using a nurse kettle to support crack sealing operations is not a new concept for Caltrans but is rarely used because sealant transfer with a standard hose is slow and can be hazardous. In addition, an extra worker is required to operate the nurse kettle for several hours typically in the yard with convenient access to the boxed sealant supply. The nurse kettle is typically transported out to the work site to make a single transfer when needed.

Chapter 2. TTLS Development Project

2.1. Sealant Transfer Concept

In light of the Caltrans safety ruling and the prospect of continued incremental improvements, any further development of equipment associated with on-site sealant block melting was terminated. The key objective remains the ability to provide the LCSM with an ample supply of hot sealant to support a continuous 2-5 mph longitudinal sealing operation. The next logical step was to focus on the development of high production off-site melting equipment and some form of LCSM nurse kettle resupply model.

In principle the sealant transfer concept represents bringing the sealant out to the site hot and ready to apply instead of the conventional approach of bringing the sealant out to the site in boxes and slowly heating them on the highway. The switch in strategy opened up new design possibilities and required a complete reexamination of previously established operational parameters.

The research goals focused on maximizing production and safety advantages, improving the transfer speed, and mitigating extra labor deficiencies through LCSM design innovations. One of the immediate advantages recognized with the switch was that the truck bed was no longer committed to transport a large supply of boxed sealant to fill the kettle. This allowed the sealant kettle to be mounted directly on the LCSM truck chassis, eliminating the trailer-sealant kettle configuration constraint. Having an onboard kettle makes for better vehicle maneuverability, simplifies the heated sealant supply passage to the applicator and has many other operational safety advantages. Not having to transport the pallets of resupply sealant boxes represents several tons of weight savings, which results in a significant reduction in LCSM truck chassis size and correspondingly enhances vehicle maneuverability.

The transfer kettle concept logically separates the LCSM into two independent systems, the application truck and a resupply kettle. The application truck has an onboard kettle and all the support systems required to conduct high-production, automated highway longitudinal sealing operations in a self-contained unit. The resupply kettle is a trailer based large capacity sealant kettle with a high-speed hot sealant transfer system.

The basic transfer kettle operating principle has the application truck sealing longitudinal highway cracks until the onboard kettle is emptied. Then the application truck is brought to the transfer kettle for high speed refilling and returned to the worksite to continue sealing. Meanwhile, the transfer kettle is refilled with sealant blocks at a safe, off-highway location nearby (see Figure 3). The capacity of the transfer kettle is much greater than that of the application kettle, such that after sealant resupply transfer, a large mass of hot sealant remains to accelerate further sealant block melting and kettle recovery. Ideally, the transfer kettle can be recovered faster than the application truck can apply the transferred load of hot sealant and return for refilling. This would essentially constitute a continuous hot sealant supply, which has been the key element of LCSM development research.

Figure 3. TTLS Sealant Transfer

The only direct way of increasing sealant kettle melt rate is to increase internal heat transfer surface area. Some kettle manufacturers use heated container panels and others use internal heating coils, but these surfaces are geometrically limited. A kettle possessing a combination of both types of heating surfaces would have superior heating characteristics, but such a kettle is not currently commercially available.

Since standard commercially available kettle technologies were a project requirement, the best strategy to ensure the greatest possible recovery rate was to size the transfer kettle much greater than the application kettle. A larger than standard sized sealant kettle can be ordered, since manufactures simply extend the kettle size proportionally. The percentage of heating surface to volume actually decreases due to the scaling principle as the kettle volume increases, which decreases overall heating efficiency.

The sealant melting production gain sought in this research project is instead associated with the principle of block melting. The heat flow into the sealant block is proportional to the contact area. The maximum melting rate is when a sealant is block completely submerged in a pool of hot sealant. Conversely, when sealant blocks are introduced too quickly in the kettle, they tend to pile up and loose contact with the hot sealant pool and melt exceedingly slow. The larger TTLS transfer kettle ensures that a sufficient pool of hot sealant remains after the transfer to guarantee maximum sealant block melting rate and the associated highest kettle recovery efficiency.

2.2. TTLS Description

In 2002, the AHMCT Research Center began a development project aimed at a new generation high production longitudinal crack sealing machine to replace the LCSM2, which had become very popular with Caltrans Maintenance. The main design goal of the new project would be to significantly increase the hot sealant production capabilities of the new machine, which was the fundamental flaw with the LCSM development. The new strategy would be to design an altogether new automated crack sealing system based on the transfer kettle method. The new equipment would be called the Transfer Tank Longitudinal Sealer (TTLS) and consist of two independent pieces of equipment to be developed together.

The TTLS project would be an entirely new and independent machine development, not reusing any parts of the existing LCSM2 machine. The TTLS development project deliverable would be a fully functional system consisting of an application truck and a transfer sealant kettle ready for testing and deployment to Caltrans Maintenance crews. As was the case with the LCSM projects, the TTLS was designed to melt and dispense common hot applied polymer modified crack sealant supplied in boxes. In an effort to accelerate development and reduce reproduction complications, only commercially available sealant melter kettles would be considered for this project. Later projects may address the added benefit of custom design kettles, but the market demand doesn't justify a manufacturer undertaking such a project at this point.

The TTLS application truck has production and capacity capabilities similar to that of the LCSM, but in a smaller far more maneuverable form. The GMC chassis has a GVW under 20 tons and a gasoline engine for the beneficial emissions restrictions. Dual steering was a manufacturer added option installed to maintain the popular feature of longitudinal sealing off either side of the vehicle. A Cleasby Mfg. 400 gallon sealant capacity propane fired melter kettle was mounted on the chassis. Electrically heated sealant passages supplied the hot sealant to a front bumper mounted longitudinal sealing applicator mechanism.

A separate 25 hp auxiliary engine provided the hydraulic and electrical power required to operate the sealing equipment. The driver could operate all aspects of the automated sealing process from inside the cab through a touch screen user panel connected to an integrated onboard Programmable Logic Controller (PLC) and a Graphical User Interface (GUI) program. The TTLS configuration and the level of control enabled the machine to conduct safe longitudinal sealing operations with a moving lane closure. A moving closure sealing operation saves the substantial cost of establishing a lane closure and significantly reduces traffic impact.

An automated anti-tack fluid spray system was deployed on the TTLS to keep the trailing support vehicles providing traffic control from sticking to the fresh sealant during moving closure operations. The TTLS application truck was designed to safely maximize longitudinal sealing capabilities. The onboard sealant kettle was only expected to have standard heating abilities. The essential increase in hot sealant production needed to match the production increase of the application truck was to be achieved by introducing the transfer kettle to the operation.

The TTLS transfer kettle, shown in Figure 4, was to be the key element to establishing a virtually continuous supply of hot sealant supply to support the high production longitudinal sealing operation. This was to be accomplished by first conducting the initial sealant transfer doubling the application truck capacity and then through efficient recovery, conduct successive transfers providing the essentially continuous hot sealant source. The capacity of the TTLS transfer kettle was initially set at 50% greater than the application kettle capacity. This leaves 33% of the hot sealant in the transfer kettle to aid with recovery.

The TTLS transfer kettle is a self-contained Cleasby Mfg. 600 gallon, trailer-based sealant melter that is propane fired. The propane supply cylinders are not directly connected to the transfer trailer to enhance operational characteristics. The overall control of the transfer kettle trailer is fully automated by way of an onboard PLC with a touch-screen user panel interface and GUI. A high-speed sealant transfer system is one of the essential elements of the transfer trailer, which will ultimately determine the success of the transfer kettle concept. The high capacity gear pump was combined with an oversized electrically heated flexible hose to produce a design sealant transfer flow rate exceeding 15 gallons per minute (GPM). This transfer rate would result in a 20-minute transfer time to completely refill the TTLS applicator truck kettle.

Figure 4. Transfer Kettle

Several transfer hose related features were developed to support automation and ensure worker safety. Since the source kettle capacity exceeds that of the target kettle, overfilling is a concern. In order to mitigate this issue, the transfer kettle PLC wirelessly tracks the application kettle sealant level and automates the sealant transfer process. Sensors incorporated on the transfer hose confirm and monitor a secure transfer hose connection and in a failsafe mode of operation will terminate sealant flow in the case of disconnection.

For a more detailed description of the original TTLS development project including in depth component descriptions, project goals and complete operational description, the interested reader is referred to the TTLS Final Report [1].

2.3. TTLS Field Testing and Results

TTLS fabrication was completed and highway testing began in April 2005. Initial road tests focused on the application truck because it can be operated solo. The initial field tests of the TTLS application truck were conducted with Caltrans District 3 maintenance crews on Highway 113, as shown in Figure 5, and afterward with District 4 maintenance crews on Highway 4.

Figure 5. TTLS Appl. Truck Sealing Hwy 113

Altogether, the application truck sealed approximately four miles of longitudinal pavement crack, consisting of both edge and between lane cracks. This relatively small trial distance was enough to verify the basic operation of the application truck and to potentially obtain basic evaluation feedback from the Caltrans maintenance crews involved with the initial testing. The majority of the longitudinal sealing was conducted in moving in-lane closures, which was one of the major goals of the TTLS project. The application truck was designed to provide the operator complete control over the sealing process from inside the truck cab, which eliminates any direct worker traffic exposure on the highway and makes in-lane longitudinal sealing operations a possibility.

Right from the first heating cycle, it was obvious that heating time of the truck kettle was going to be a major problem. Commonly available sealant kettles require two to three hours to heat from ambient to sealant pour temperature. The Cleasby Mfg. Co. sealant kettle purchased and mounted on the TTLS application truck was requiring three to four times longer than normal to heat-up.

Since the most important and fundamental objective of the TTLS concept was to increase the hot sealant supply, a slow heating kettle is a fatal flaw. The cause of the problem was determined to be manufacturer error and cannot be repaired. The protracted kettle heating time renders the application truck effectively useless for continued testing, or any realistic form of field deployment duty. Complete kettle replacement is the only viable option to enable the TTLS applicator truck to achieve field deployment status. The first half-dozen transfer trailer heating tests were prematurely terminated due to kettle heat transfer oil leaks. It took several attempts for the manufacturer to repair all the leaks.

Once a full heating cycle could be completed, it was determined that the Cleasby Mfg. kettle was also slower than normal to heat up to operating temperature. Trailer heating tests took more than twice as long to heat up to operating temperature than expected. Slow heating degrades the performance of the transfer trailer but does not represent a fatal flaw. The first sealant transfer each day to the application truck kettle is feasible, but the possibility of any subsequent transfers seems unlikely. All other systems on the transfer trailer are working as designed. During initial operational testing, three hot sealant transfers were successfully performed to refill the TTLS application truck kettle off of the highway.

Chapter 3. TTLS Upgrade Project

3.1. TTLS Operational Deficiencies

Field testing of the TTLS application truck was stopped prematurely due to substandard sealant kettle heating performance. The expected 1-3 hour heat up time was taking over 5 hours and still not reaching full operating temperature. Unfortunately, the cause for the deficiency was due to faulty kettle design, which could not be repaired or improved. The only viable option to mitigate the application truck kettle heating problem would be kettle replacement. Since the truck kettle is fairly self-contained and utilizes minimal chassis mounting, swapping-out the kettle alone was a viable option. The electrical and control systems would be reusable and the application systems would have been unchanged.

The transfer trailer kettle heating times appear to be twice as long as expected. The fast heating and operational abilities of the transfer trailer are far less critical than the application truck to overall TTLS performance and production. The transfer trailer heating and sealant recovery performance is the key factor in achieving multiple sealant transfers per day. Ideally, replacing both kettles would be optimum, but replacing the trailer kettle would require an entirely new machine be built and is of a lower priority.

3.2. TTLS Improvements

The TTLS operational deficiencies were preventing further highway testing and had to be mitigated. At a minimum, the application truck kettle had to be replaced and the system rebuilt. Caltrans Maintenance pledged support for the TTLS rebuilding project with the condition that specific features were to be incorporated in the new design. The most remarkable of these requested features was the addition of manual in-lane sealing capabilities.

Caltrans had long been discussing the merits and limitations of a longitudinal only crack sealing machine. The addition of a manual sealing hose would settle the dispute by enabling this one machine to seal all types of pavement cracks. The other requested improvement was to add compressed air crack cleaning capabilities. No improvements to the transfer tank were to be undertaken until the application truck was rebuilt and returned to field testing. Sequent field testing of the transfer tank system with the application truck would be required to better evaluate system performance and possible design improvements. Caltrans supported the TTLS modification project, which began in February 2006 with the dismantling of the TTLS application truck.

3.3. Bearcat Kettle Replacement

The substandard sealant kettle on TTLS application truck was replaced with a Bearcat Mfg. 400 gallon propane fired kettle (see Figure 6). All previous versions of the LCSM equipment exclusively used Bearcat sealant melting kettles. These kettles appear to have the fastest heating times of any other kettles that Caltrans maintenance crews have operated. The Bearcat kettle design also contains a unique heating scheme, which places all heating surfaces inside the lower half of the sealant vat. This proved to be a very useful attribute in LCSM deployments in the past, since operational issues prevented the kettles from being kept full during highway operations.

The Bearcat kettle provided full heating capabilities even when the vat was half empty. All other kettles with standard surrounding oil jacket designs lose heating capabilities proportionally with the reduction in sealant level. Due to emissions limitations, traditional diesel fired burners are no longer acceptable to Caltrans. The switch to propane burners is the new requirement, which has caused freezing problems for ordinary vapor burners due to the high gas flow rate. The switch to liquid propane burners seems to have mitigated the freezing problem.

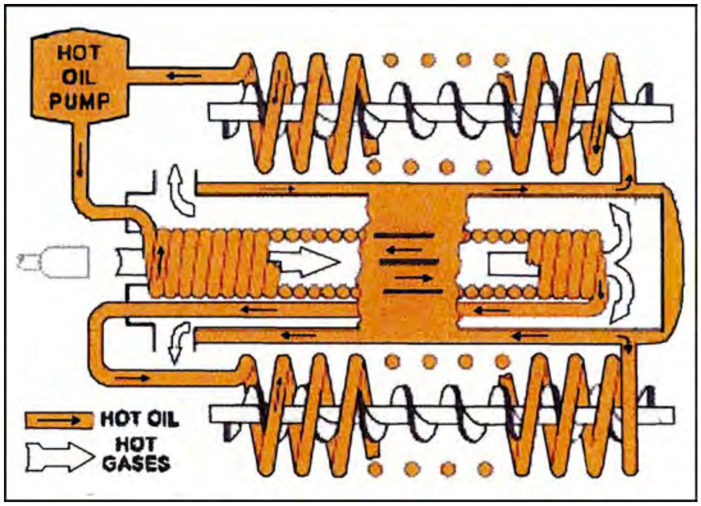

Figure 6. Bearcat Sealant Melter Kettle

The TTLS operational scheme is predicated on the ability to run the sealant kettle empty. Running any kettle empty is problematic and is typically a practice to be avoided. The transfer principle of supporting high production crack sealing operations has evolved to a point where empty kettle operation has become a necessity. Latent heat and exposed heating surfaces increase internal coking concerns for a kettle run empty. Recovery of an empty kettle refilled with sealant blocks is far slower without the benefit of a remaining hot sealant mass. The empty recovery is not typically an issue with the TTLS because the truck kettle is to be primarily filled via hot sealant transfers, but the coking issue must be mitigated. Heating surface exposure does not become a concern with the Bearcat kettle until it is more than half empty. Also since the Bearcat heating coils depend on heat transfer oil circulation to radiate heat, reducing the oil circulation provides a quick means of controlling exposed heating surface temperature. In this way, the machine controller could be employed to automatically control the coking potential as the kettle is run empty.

3.4. In-Lane Sealing Capabilities

There was a growing criticism within Caltrans that even though longitudinal sealing machines had consistently performed at dramatically increased seal production rates, the longitudinal only sealing limitation was reducing the overall usefulness of the equipment. Therefore, the TTLS upgrade project would include the addition of a standard heated sealant hose and wand assembly to support in-lane sealing operations. The in-lane sealing would be a manual operation similar to the current standard hand applied in-lane sealing operation. Since the longitudinal sealing process is a continuous process that can be conducted in a moving lane closure, as shown in Figure 7, and the manual in-lane sealing operation is a stop and go process that definitely necessitates a fixed temporary lane closure, these two sealing operations could not be performed simultaneously. Furthermore, the TTLS onboard kettle configuration enables the machine to run in reverse on the highway providing additional protection from worker traffic exposure and also benefits sealing production efficiency.

The addition of a sealant hose and a manual application wand necessitated a complete redesign of the applicator bar mounted on the front bumper of the application truck. The new combined applicator design creates a single, heated sealant passageway that incorporates a commercially available electrically heated sealant hose to reduce fabrication and replacement costs. The hose is mounted at the front of the truck and connected to the kettle through an oversized, electrically heated sealant passage. A front bumper mounted hose basket was developed to contain and protect the sealant hose and wand assembly. A removable support boom can be attached to the bumper basket frame as needed to support the sealant hose off the ground during manual sealing operations.

Figure 7. TTLS Moving Closure Sealing Hwy

Inclusion of the heated sealant hose improves the sealant passage heating process by providing the capability to re-circulate sealant through the heated hose and back into kettle. This feature may not be considered a basic necessity when using an electrically heated hose, but past experience has proven that having hot sealant recirculation capability is a very useful benefit for start-up and idle phases. A hose recirculation cradle was developed to safely support the application wand during recirculation operations. A fail-safe mode of operation was developed with sensors that monitor the safety of the wand connection throughout the recirculation process. The 20 ft long sealant hose selected for this project is the longest commercially available heated hose and will provide for full lane width access for manual sealing operations off the front of the truck.

3.5. Crack Cleaning Capabilities

The effectiveness and longevity of seal performance is primarily a function of sealant to pavement adhesion. In order to promote sealant adhesion, the pavement crack surfaces should be free from dust and debris. The most cost effective and common pavement preparation technique is a blast of compressed air to blow dust and debris out of the crack just prior to the application of sealant. In past LCSM operations, Caltrans often ran a separate vehicle ahead of the operation towing an air compressor to blow the crack out. For heavy cleaning, the crack would be blown out days ahead of the scheduled sealing operation followed by a sweeper truck. Adding a large capacity air compressor to the application truck provides the option of blowing the crack clean just prior to sealing with a single vehicle (see Figure 8). Heavy cleaning should be conducted ahead of time to keep the debris from sticking to the fresh sealant, but a light dusting of the crack would be appropriate and beneficial.

Figure 8. Longitudinal Crack Cleaning

The power required to run a large capacity air compressor would necessitate the change to a far larger auxiliary engine. The TTLS application truck had a 24 hp auxiliary engine, which provided barely enough power to drive the hydraulic pump and electrical alternator. The addition of a high capacity rotary screw compressor and AC generator to power the electrically heated hose necessitated doubling the power of the auxiliary engine. The application truck component layout had to be changed to account for the weight and size of the far larger auxiliary engine, and a custom housing was engineered to mount these four power systems on the engine's single output shaft.

Chapter 4. Sealzall Description

4.1. Basic Description

Upgrading the TTLS application truck to include manual in-lane crack sealing capabilities, represented a clear departure from the longitudinal only nature of the previously deployed machines. Consequently, the name of the rebuilt TTLS application truck was changed to the Sealzall machine.

Caltrans supported the Sealzall development project, which included the TTLS redesign, development and initial deployment of the Sealzall application truck for use by Caltrans Maintenance. The chassis, hydraulic system and a large portion of the TTLS application truck electrical system would form the foundation for the Sealzall machine development.

A standard 400 gallon Bearcat kettle was then mounted mid chassis, and the auxiliary engine assembly was mounted at the rear of the stripped down TTLS chassis. A guided radar wave liquid level sensor was mounted in the kettle to provide an accurate measure of sealant level to the PLC and GUI. An 86-gallon propane cylinder was mounted side saddle on the right rear side of the chassis to supply fuel to the liquid propane burner, which was added to the sealant kettle. A modified Cimline electrically sealant hose and wand assembly was mounted in the center front of the truck and connected to the melter through an electrically heated and rigid tubing passageway. A basket mounted to the front bumper was developed to carry the heated sealant hose. Underneath the hose basket is a carriage mechanism that holds and controls the sealant wand for high production longitudinal sealing operations.

The wand carriage assembly is movable and can be configured off either side of the truck for longitudinal operations with a push of a button. The sealant wand has a quick release connector tip so it can be easily reconfigured for different operations. A shoe mechanism quickly attaches for longitudinal operations, a disk for manual sealing operations, or the wand can be securely clipped onto the kettle for sealant recirculation.

4.2. Basic Operational Description

The Sealzall machine, shown in Figure 9, is a completely self-contained pavement crack sealing system capable of automated longitudinal and manual in-lane sealing operations. The TTLS transfer kettle can be operated in conjunction with the Sealzall operation in order to augment hot sealant supply as needed. Sealzall operational control is automated to simplify operator training and improve operational efficiency. An in-cab touch screen display and GUI forms the simple operator interface to the PLC unit, which directly and automatically operates all the necessary onboard sealing and support systems.

Figure 9. Sealzall Machine

The Sealzall operates on its own electrical system powered by the auxiliary engine, which is separate from the truck chassis electrical system. Sealzall systems including the GUI become active when the auxiliary engine power is switched on. The first step in conducting Sealzall sealing operations is the system heating and filling process stage. A fully automated heat up cycle process has been developed for the Sealzall machine, which reduces the complex series of events required to initiate and monitor the various control loops, pumps, motors and valves that comprise the heating system, down to a single a push of a button on the GUI.

The Sealzall heat up process takes about an hour and a half for all necessary systems and the sealant to reach operational temperature and transition into the recirculation phase. The operator then mounts the sealant wand in the recirculation cradle on either side of the truck and with another push of a button on the GUI, the hot sealant is circulated through the entire sealant passage and back into the kettle.

The kettle sealant level is typically topped off during the heat up process by physically dropping sealant blocks into the top loading hatches on the kettle. Starting with a completely full sealant kettle is recommended in order to maximize Sealzall sealing production capabilities. With the Sealzall heated, filled and recirculating sealant, the machine is then ready to be configured for either longitudinal or in-lane sealing operations to begin highway sealing operations.

4.3. Longitudinal Sealing Enhancements

The Sealzall redesign maintained all of the popular TTLS longitudinal sealing control features and capabilities with the addition of a few enhancements. Of these, the replacement of the TTLS applicator bar with a sealant hose wand assembly provided the greatest benefit by establishing the ability to re-circulate hot sealant from the kettle through the entire electrically heated sealant passageway and back into the kettle. Electric passage heaters ordinarily provide only enough heat to melt sealant enough to get it flowing or help maintain passage temperature at idle flow, but cannot provide nearly the energy required to heat the sealant passage up to application temperature alone. Hot sealant recirculation is the best method to assure full sealant passage temperature at start-up and during operational idle times. For example, the TTLS without recirculation capabilities routinely required the dumping of sealant through the applicator on the side of the roadway at startup in order to get the passages fully heated. The Sealzall in its longitudinal sealing configuration is shown in Figure 10.

Figure 10. Sealzall Longitudinal Sealing

Another Sealzall longitudinal enhancement was the addition of lateral sealing shoe adjustment. Caltrans operators have long been requesting the ability to vary the distance the sealing shoe extends laterally from the side of the truck. On the open road the shoe can extend 2 feet for easy operator viewing, but in tight spaces, the shoe can be brought in as close as 1 foot, or positioned anywhere in between. The operator can make the lateral adjustment on the fly from the user panel as needed to help avoid obstacles. Since the sealing shoe can extend up to 2 feet from the side of the application truck, this can present a visual obstruction to adjacent traffic. Since longitudinal sealing operations are often conducted on the boundary between live traffic lanes, the potential for a passing vehicle of hitting the sealing shoe had to be mitigated. The solution employed on the Sealzall is to extend a visual barrier out off the rear side of the application truck during longitudinal operations as far out as the sealing shoe. This makes the Sealzall appear wider to approaching traffic and drivers will instinctively steer clear reducing the risk of hits.

One of the most requested features to be added to the TTLS during Caltrans testing was crack cleaning capability with compressed air. Therefore, the size of the Sealzall auxiliary engine was increased to support the operation of a high volume rotary screw air compressor. The onboard high-pressure air system can be used for crack cleaning and at the same time supply various pneumatically operated crack sealing systems. Air hose connections are available on the front, rear and sides of the vehicle. For major cleaning operations, air nozzles are configured on the side and rear of the vehicle. Should heavy crack cleaning be required, a separate cleaning operation is typically conducted days ahead of the sealing operation and followed by a sweeper machine. Front nozzle hardware has been developed to support crack dusting just ahead of sealant application for longitudinal operations and can be operator selected for automatic control.

4.4. In-Lane Sealing Enhancements

The key innovative feature of the Sealzall was the addition of a sealant wand to provide for manual in-lane crack sealing capabilities. The in-lane sealing operation is comparable to traditional manual method with some additional enhancements (see Figure 11). First, since the Sealzall machine is designed to operate using the TTLS sealant transfer scheme, sealant block handling and loading on the highway is eliminated. Instead the kettle is emptied by the manual sealing operation and quickly refilled by means of high-speed hot sealant transfer from the transfer kettle trailer.

Figure 11. Sealzall In-Lane Sealing

The unique truck mounted sealant kettle configuration of the Sealzall produces some inherent operational advantages. Typically, a manual sealing crew follows behind a truck and trailer mounted sealant kettle when sealing cracks manually. This traditional configuration does not enable the driver to directly see the sealing crew. The driver must rely upon hand signals, provided by the workers, which guides the driver as to when to drive forward and when to stop. Ideally for safety, an extra worker is added to the operation on the highway in order to handle the signaling duties.

The traditional configuration also necessitates that the truck be turned around and run in a direction opposing highway traffic for safety reasons thus enabling an attenuator truck to shield the operation. The California Highway Patrol is routinely called to run traffic brakes in order to enable Caltrans crews to turn their truck and kettle trailer sealing rig around on the highway. The Sealzall onboard sealant kettle configuration enables the vehicle to back-up in the lane closure while facing in the forward traffic direction thus providing the driver a direct up front view of the sealing crew. This unique backing configuration enables the Sealzall to enter, seal and exit the lane closure all in the normal direction of traffic, simplifying lane closure operations. An additional benefit of sealing with the truck pointing in the normal direction is that should a vehicle hit the Sealzall, the truck body would provide better protection to the driver compared to a head-on collision.

Generally, in-lane crack cleaning sealing operations include crack cleaning with a blast of compressed air before the application of sealant. The Sealzall has a compressed air connection on the front bumper and an onboard air hose and wand that can be used to conduct a tandem manual in-lane cleaning and sealing operations. In this way two workers can collaborate together to blow clean and seal in-lane cracks as the operation travels along the lane.

4.5. Moving Closure Sealing Operations

The Sealzall application truck is designed to have the unprecedented ability to conduct longitudinal crack sealing operations in a moving highway lane closure operation. Moving lane closures save the significant cost of establishing, maintaining and removing fixed lane closures and reduce the associated risk to traffic and maintenance personnel. In addition, moving lane closure operations present less of an impact on traffic congestion and enable the sealing of longitudinal cracks between lanes, which are often unreachable with fixed temporary traffic closures. Many of the TTLS initial highway tests were conducted in moving closures, which provided the opportunity to test and evaluate moving closure support systems.

The Sealzall is typically heated and configured off of the highway and then driven into live lanes protected by a following train of traffic control vehicles. The longitudinal shoe is deployed when in the lane and sealant applied as the machine drives along the edge crack to be filled at a continuous 2-5 mph. At any point the shoe can be lifted and the Sealzall driven off the highway.

The operator/driver has complete control of the entire longitudinal sealing process from inside the truck cab and is never directly exposed to traffic due to the in-cab user interface shown in Figure 12. Should any unexpected problems occur on the highway during sealing, the vehicle can be quickly and easily driven off of the highway to address the issue. Should heavy traffic conditions create a problem with such a slow speed closure, a strategy of multiple passes while circling around exits can be easily employed to seal sections of highway.

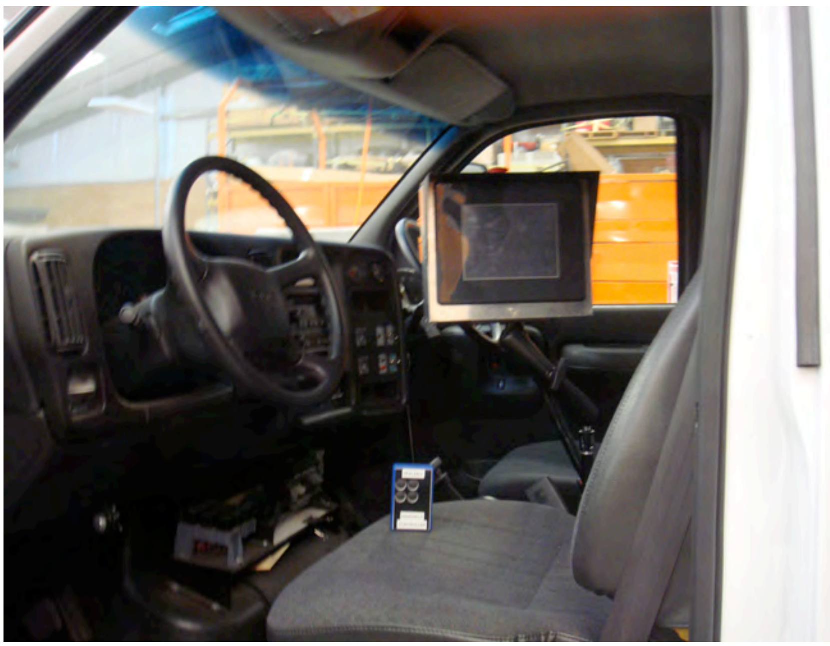

Figure 12. Sealzall In-Cab GUI

An anti-tack spray system was first deployed and tested on the TTLS to prevent trailing vehicles from pulling fresh sealant up off the road and fouling vehicle tires. An upgraded anti-tack spray system was developed for the Sealzall, which can be user selected to automatically spray when sealing. The Sealzall spray system improvements included the incorporation of more efficient spray nozzles with built-in check valves, which reduces excess dripping, tank contents mixing capability and improved spray flow rate fine adjustment control. Several liquid detack products are commercially available, so the operator can choose their product and mixture of preference.

4.6. Initial Testing

The Sealzall machine initial development was completed in June 2009. The machine is fully functional and undergoing operational verification and evaluation. The high production nature of the Sealzall machine, combined with the sealant's innate short lifespan at application temperature, makes small scale testing impractical. It is essential that initial Sealzall functional sealing testing be conducted on the highway with Caltrans Maintenance crew's support where large amounts of sealant can be run through the machine. Successive heating of the machine without replacing the sealant will lead to sealant coking and if not accounted for could ruin the kettle. The initial testing will include longitudinal and in-lane sealing operations in both fixed traffic closures and moving lane closure operations. Ultimately, following any required adjustments discovered in the initial testing phase, the Sealzall will be turned over to Caltrans Maintenance for general deployment service with continued field support provided by the AHMCT Research Center.

4.7. Commercialization

The Sealzall project focused equally on both the functionality and reproducibility on component designs keeping with the original reproducibility initiative started with the TTLS development project. Sealzall fabrication work was subcontracted to manufacturing companies as much as possible to establish possible future sources for component reproduction and to assist with the potential building of additional machines for Caltrans. Vendors were selected on the basis of their experience, credibility and wiliness to reproduce their services. Additional Sealzall machines could be either manufactured piecemeal or assembled at Caltrans, or some vendors have expressed interest in providing complete Sealzall machines to Caltrans. Subcontracting fabrication work also ensures that detailed manufacturing drawings, electrical diagrams, fluid system schematics and parts lists have been developed throughout the development process.

Chapter 5. Sealzall Machine Operation

5.1. Basic Startup and Operation

The Sealzall system is independent of the truck chassis platform except for the auxiliary engine, which shares fuel from the vehicle's 45-gallon gasoline fuel tank. An 86-gallon propane fuel tank is mounted on the chassis to fuel the Sealzall sealant kettle's burner. Both of these fuel tanks should be full prior to beginning a normal day's sealing operation with the machine.

Since the Sealzall system has an independent electrical system and battery, the truck chassis ignition does not have to be on when running the Sealzall system. This saves fuel during the heat up stage and reduces hours on the truck engine. The key switch on the auxiliary engine (see Figure 13) activates the Sealzall electrical system in accessory mode and also starts the engine as in a typical ignition switch operation. The Sealzall controller automatically varies the speed of the auxiliary engine based on the power demand. The engine runs at idle unless specific high power systems are engaged at which point the engine is brought up to full speed.

Figure 13. Ignition Switch On Auxiliary Engine

The key switch can also be turned to accessory mode to activate the Sealzall electrical system and GUI without starting the engine. In this case or in the case of engine failure during operation, the **START SCREEN** is displayed on the GUI (see Figure 14). Normally, the standard first step in Sealzall operation is to start the auxiliary engine and when running, the **SETUP SCREEN** is displayed on the touch screen GUI (see Figure 15) that is mounted in the truck cab. The GUI convention is that features displayed with a raised appearance display frame are buttons that can be activated with a press of a finger on the touch screen surface. The flat looking features without a display frame are indicators only. The turquoise **INFO? BUTTONS** when pressed present additional, associated functional information.

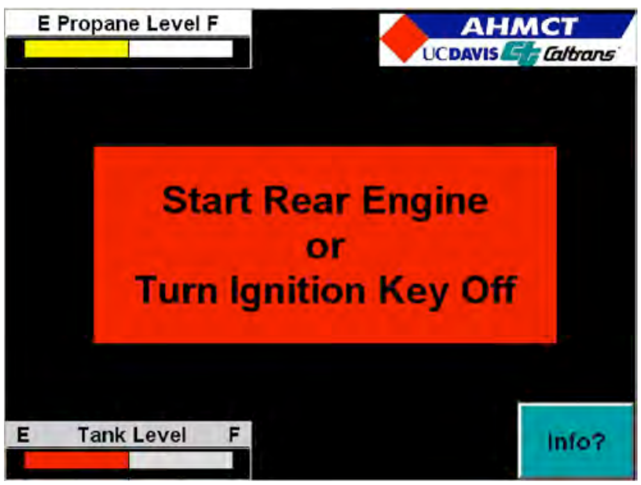

Figure 14. GUI Engine Start Screen

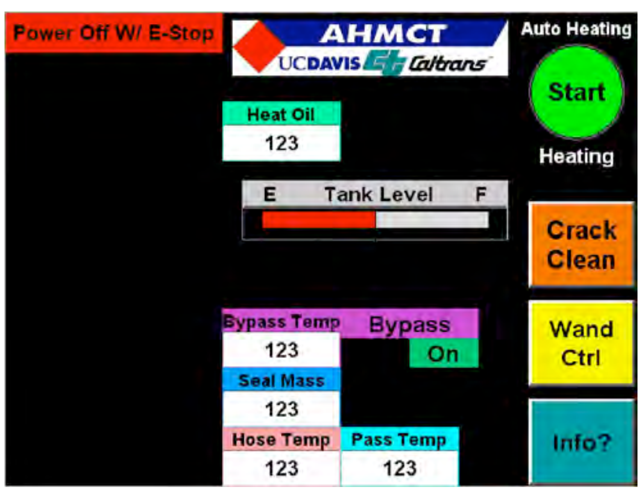

Figure 15. GUI Root Set-Up Screen

The Sealzall truck has three emergency stop buttons, which leaves the controller and GUI running but immediately stops all Sealzall action systems, including the auxiliary engine. One E-button is located in the cab on the top of the GUI case, and the other two are located on either side of the chassis toward the rear. When the E-stop button is pressed, it remains engaged and the GUI displays the **E-STOP SCREEN** (see Figure 16). To reset the E-stop condition, the E-stop switch must be twisted to release the switch. When all the E-stop switches are reset, the GUI returns to the **START SCREEN** indicating that the auxiliary engine needs to be restarted. For safety reasons, should the controller detect an error with any of the temperature thermocouples, an E-stop condition will be triggered automatically. The **E-STOP SCREEN** will appear, indicating which thermocouple is faulty.

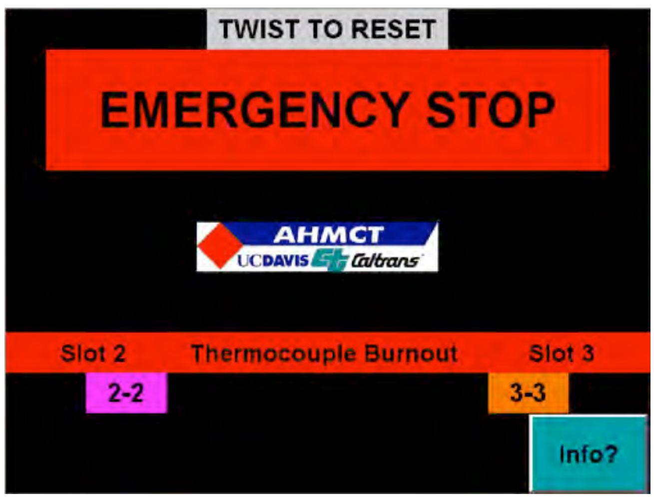

Figure 16. GUI E-Stop/Fault Screen

The Sealzall chassis has dual steering controls to support longitudinal crack sealing operations off either side of the vehicle. Caltrans recommends that dual steer vehicles be driven from the left side under normal driving conditions and driven on the right side only when necessary. Typically, right side driving is limited to within the workzone. The GUI is mounted on an adjustable mounting so it can be easily configured for access to either side of the cab with the loosening of a clamp.

5.2. Crack Cleaning Operation

Dirt, debris and vegetation tend to appear more in longitudinal edge cracks than in-lane cracks, primarily due to traffic effects. Often, separate crack cleaning operations are conducted days ahead of the sealing operation to prepare the site. The Sealzall system has a high-pressure and high-flow rotary, screw air compressor incorporated on the auxiliary engine designed specifically to support this type of crack cleaning operation.

With the engine running, the crack cleaning button can be selected on the GUI **SET-UP SCREEN** to configure the Sealzall for crack cleaning only mode. The **CRACK CLEANING SCREEN** is displayed on the GUI where the operator can engage the air compressor, which automatically speeds up the auxiliary engine. Then the **AIR FLOW BUTTON** appears (see Figure 17), which enables the operator to control the air flow to the nozzles from inside the cab.

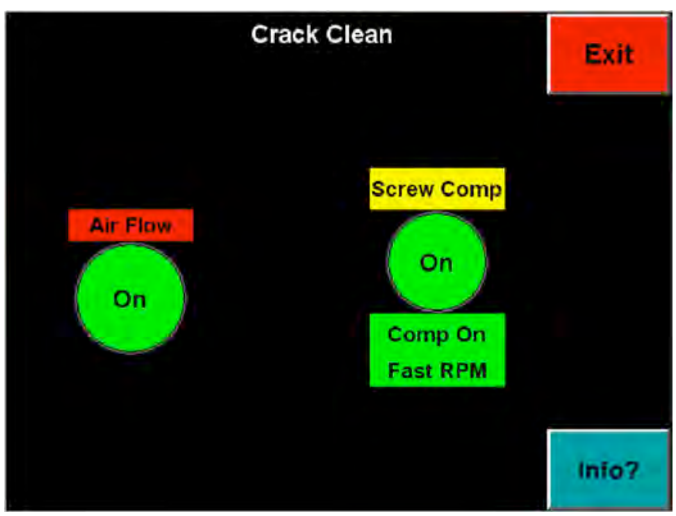

Figure 17. GUI Crack Cleaning Screen

The common Sealzall longitudinal cleaning configuration utilizes two nozzles. One nozzle is mounted on the side of the vehicle and the other on the rear bumper. The side nozzle provides the driver a direct line of sight to steer the vehicle such that the nozzle delivers a blast of air directly into the crack. Research has shown that the effectiveness of crack cleaning diminishes precipitously when the air blast is offset from the crack by as much as an inch. The Sealzall side nozzle is mounted in line with the front axle to provide exceptionally responsive control for the driver to accurately follow the longitudinal crack. The driver can also vary the speed of the vehicle to provide the level of cleaning required. The rear nozzle blows the debris ejected from the crack off the side of the roadway. Generally, a sweeper follows up the cleaning operation to remove debris from the roadway, thus reducing the chance that it may be picked up by traffic and break windshields.

The same principle of air blast cleaning of cracks to promote seal quality applies to in-lane crack sealing operations as well. The Sealzall has a single compressed air connection on the front bumper basket and an air hose/wand assembly designed to support the practice of manual in-lane crack cleaning. The Sealzall supports the deployment of a second worker to blow out cracks before the in-lane cracks are sealed. Both operations can take place simultaneously in the workspace in front of the Sealzall truck. The driver can only enable and supervise the manual sealant and air systems with the GUI and can stop these systems if necessary. The workers holding the wands maintain sole control to start the flow through either of these systems. Press the **RETURN** button on the GUI to return to the **SET-UP SCREEN**.

5.3. Auto Heating Procedure

With the auxiliary engine running and the GUI displaying the **SET-UP SCREEN**, the Sealzall system is ready to begin the fully automated heating cycle. The operator simply presses the **AUTO HEATING BUTTON** (see Figure 18), and the control program manages and controls the correct component heating sequence to bring the Sealzall system up to sealing operational temperature and maintain sealant application temperature. If starting cold, the controller starts the propane burner, followed in a few minutes with the activation of the heat transfer oil circulation pump. The auxiliary engine stays at low-speed idle up to this point, but will automatically speed up to maximum power when any of the next components are activated. Usually, the passage heaters are started next, which triggers the engine to speed up to maximum power and automatically engages the screw air compressor.

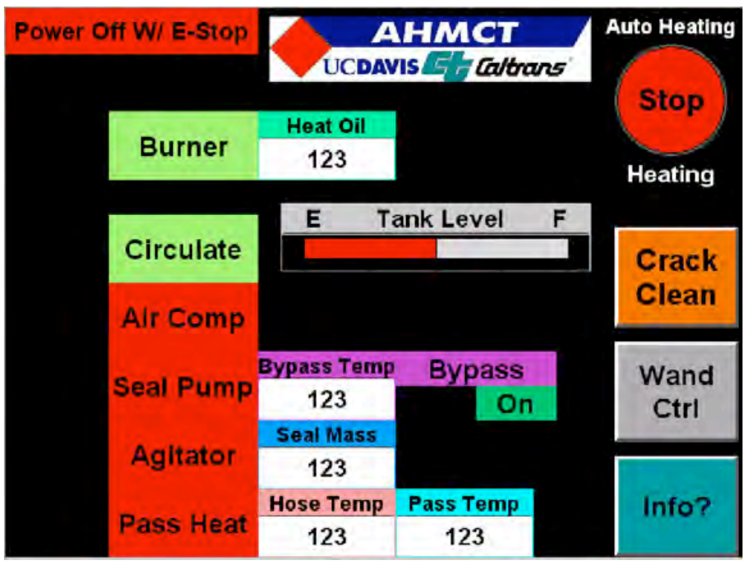

Figure 18. GUI Auto Heating Screen

A high pressure storage tank mounted under the chassis provides compressed air to operate the bypass and sealant wand actuators. The sealant pump is activated next when it reaches operation temperature. First, the sealant pump runs in reverse to promote additional heating and then runs forward circulating hot sealant through the sealant bypass passage. The bypass flow pumps hot sealant on top of the sealant mass accelerating overall kettle heating. When the sealant mass is sufficiently melted, the sealant agitator augers are activated to circulate the melted sealant over the heating coils.

With all of the Sealzall heating systems activated, **WAND CTRL BUTTON** turns from gray to yellow (see Figure 19) indicating that all sealant operation temperatures have been reached. Absolutely, the last step to complete the heating process is to recirculate hot sealant through the sealant wand and passages. The operator presses the yellow **WAND CTRL BUTTON**, and the GUI displays the **WAND CTRL SCREEN**. The operator next selects the **RECIRCULATION BUTTON**, and the GUI indicates that the sealant wand needs to be mounted in the recirculation cradle (see Figure 20). The operator must then remove the sealant wand and hose from the front bumper basket and lock the wand into the recirculation cradle on either side of the vehicle (see Figure 21). The tip of the sealant wand clips onto the kettle and the wand rests on a supporting cradle.

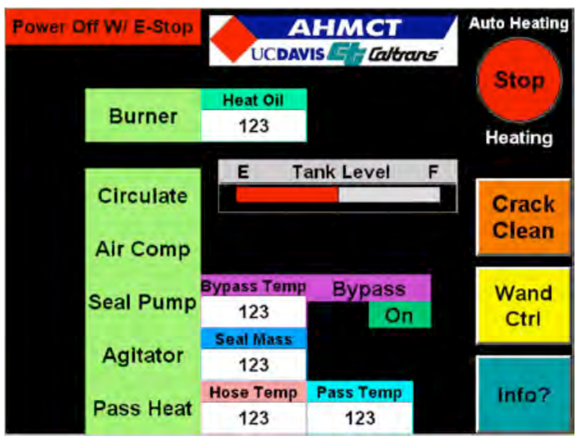

Figure 19. GUI Auto Heating Screen

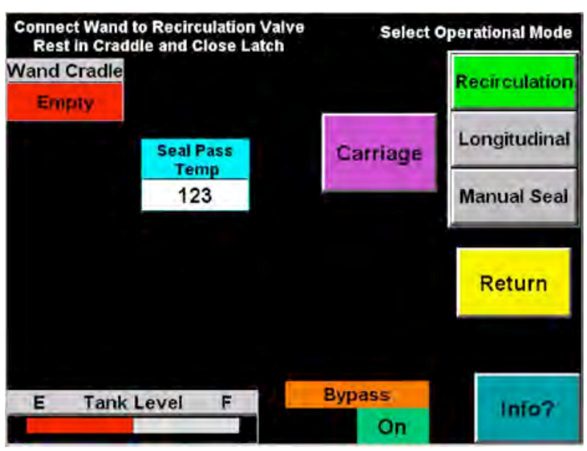

Figure 20. GUI Recirculation Screen W/O Wand

The operator must then pull the safety latch and flip it over the wand until the green LED indicator illuminates verifying the wand is properly connected. This sends a signal to the controller that the wand is configured for recirculation, and the GUI display instructs the operator to press the wand seal flow button X3 on the wand (see Figure 22) to begin the recirculation sealant flow. The green LED indicator on the cradle flashes while the seal flow is active and the GUI display changes providing additional tools to help the operator establish sealant flow (see Figure 23).

Figure 21. Sealant Hose Recirculation

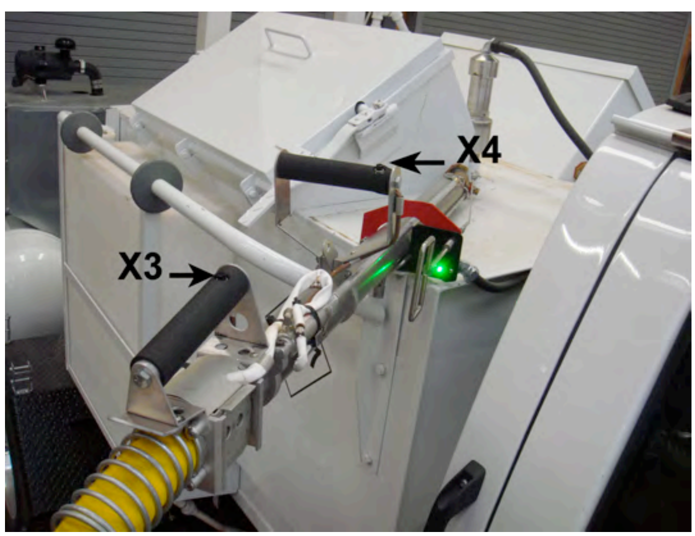

Figure 22. Wand Mounted in Recirculation Cradle

If the electric heaters have sufficiently heated the sealant passages, hot sealant from the kettle will flow through and re-circulate back into the kettle. The temperature of the passages will then quickly rise to the sealant kettle temperature as the hot sealant starts to flow. This temperature rise indicates to the operator that recirculation flow has been established and the Sealzall is ready for sealing operations. Pressing of the wand flow button X4, or the **SEAL OFF BUTTON** on the GUI, stops recirculation flow. Opening the recirculation cradle latch causes the green LED to go off and will also stop and reset recirculation flow.

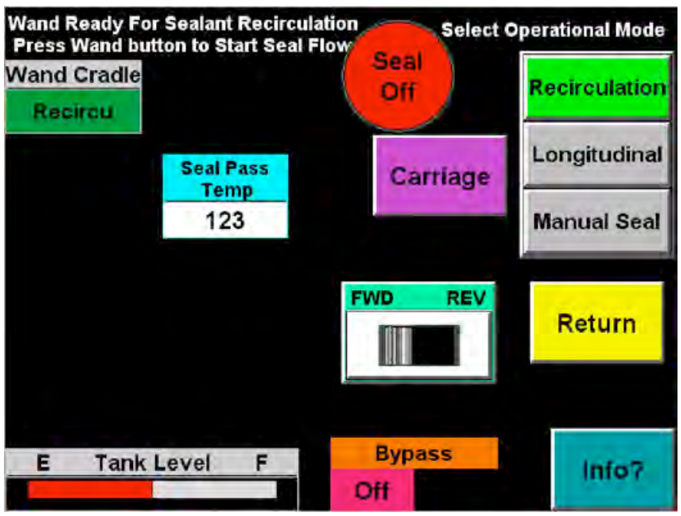

Figure 23. GUI Recirculation Screen W/Active Flow

If either the sealant or the passages were not sufficiently heated, the hot sealant recirculation flow can be blocked. The operator will generally recognize the blockage when the sealant passage temperature fails to rise up to near the sealant mass temperature. The best method to remove the blockage is for the operator to toggle the sealant pump direction **FWD/REV BUTTON** (see Figure 23) until the blockage is removed and the passage temperature rises. Reversing the pump draws back the sealant that has cooled in the passage, and then switching to forward fills the passage with new hot sealant from the kettle. Repeating the process every minute or so effectively melts the cold spot blockage and gets sealant flowing. In general, it is common practice to return the sealant wand to the cradle and recirculate hot sealant during extended pauses in sealing operations lasting more than a few minutes to maintain optimum sealant passage temperature. In the case of moving lane closure operations, the vehicle is typically driven off the highway to deal with recirculation.

5.4. Heating Procedure Overrides

Under normal operating conditions, Sealzall operators follow the simple Auto heating program steps and when the Sealzall is up to operational temperature, the machine is configured for the desired sealing process. The Sealzall GUI also provides the operator with additional override capabilities, informational screens and access to program control set-point data.

To return to the **HEATING SCREEN** at any time to access heating controls, the operator can press the yellow **RETURN BUTTON** (see Figure 23) and the GUI returns to the **AUTO HEATING SCREEN**. Pressing any of the process control buttons starting from the **BURNER BUTTON** and running down vertically to the **PASS HEAT BUTTON** (see Figure 19) will switch the GUI to an override screen associated with that process (see Figure 24). The process override screens enable the operator to see additional process information and override process auto control to force the process on or off.

The default mode of operation is **AUTO**, indicating the program has control, but selecting **ON/OFF** on the **OVERRIDE SCREEN**s gives the operator direct control. To emphasize to the operator that a component or system is no longer under automatic control, a **RESET BUTTON** appears next to the corresponding process button (see Figure 25).

The override condition can be returned to automatic program control in one of two ways. From the **AUTO HEAT SCREEN**, pressing the **RESET BUTTON** will put the component back under program control, or from the override screen press the **AUTO** button to accomplish the same objective.

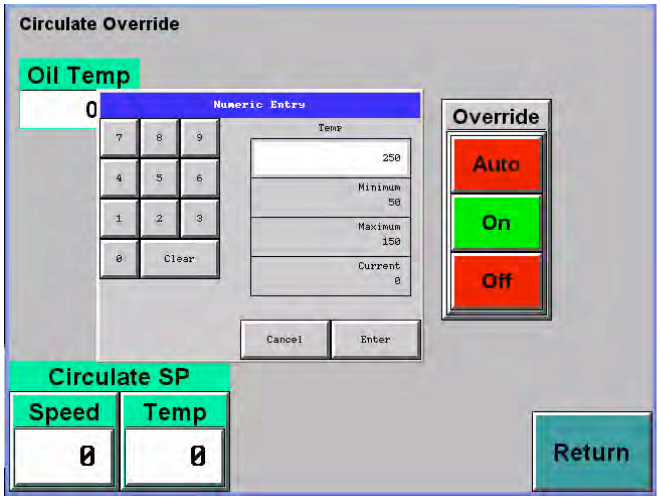

Figure 24. Circulate Override and Data Entry Screen

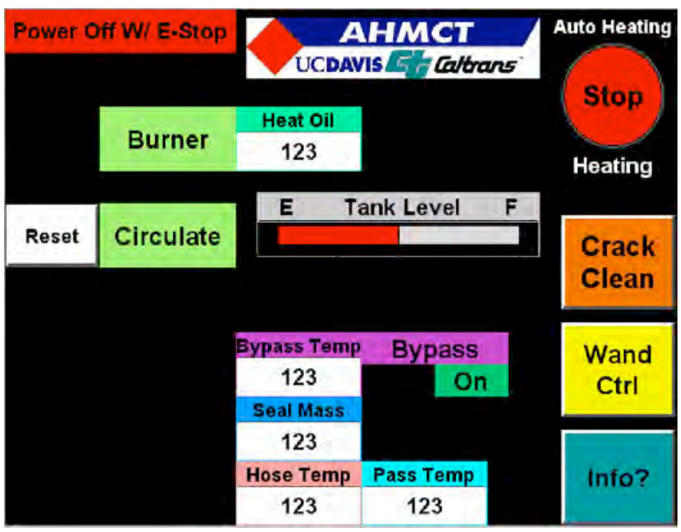

Figure 25. Override Condition – Auto Heat Screen

The override screen also provides access to non-critical sensor and set-point data. Sensor information includes additional component, mechanical configuration and system temperature readings, which are not essential to normal operation. Operators can access the program set-points, which dictate automatic control characteristics through the override screens. GUI numeric data that can be changed by the operators are features that have a raised appearance display frame. Pressing these buttons brings up a numeric entry screen (see Figure 24) allowing the entry of a different set-point value.

5.5. Sealing Operation Procedures

The ordinary Caltrans crack sealing machine operations begin with the kettle heated in the maintenance yard. Sometimes an operator arrives early to begin heating, but since highway tasks usually start after the morning traffic has ended, normal starting times are usually sufficient. The goal is to have the Sealing machine fully heated, filled with sealant, and ready to begin highway sealing operations as the morning traffic window opens.

As the machine is heating, the maintenance crew can coordinate the operation personnel duties and traffic control. It is recommended to progress through the recirculation stage before bringing the machine out of the yard. Establishing hot sealant flow through the hose in the yard ensures the highest probability that the machine will function out on the highway. Some operators go so far as to keep the sealant re-circulating through the hose in transit to the work site to be absolutely sure sealing operations will be successful.

Caltrans safety policy allows for the practice of sealant circulation in transit but expressly prohibits the propane burner from operating as the vehicle is driven on the road. Therefore, as the vehicle leaves the yard, the operator must press the **TRANSPORT BUTTON** (see Figure 26) and the control program will automatically configure the Sealzall for safe transport. Upon arrival at the work site, the **TRANSPORT BUTTON** is pressed again, the Sealzall returns to full operation, and the propane burner is enabled.

Upon completion of sealing operations, it is recommended that the Sealzall system be completely shut down immediately, saving kettle sealant life. Pushing one of the E-stop switches is the quickest and simplest method. It is highly recommended that upon returning to the yard post operation, the Sealzall kettle is refilled to capacity with sealant blocks. The residual heat in the kettle will efficiently melt these sealant blocks as the kettle slowly cools. This tactic greatly simplifies the subsequent refilling of the kettle during the heating process.

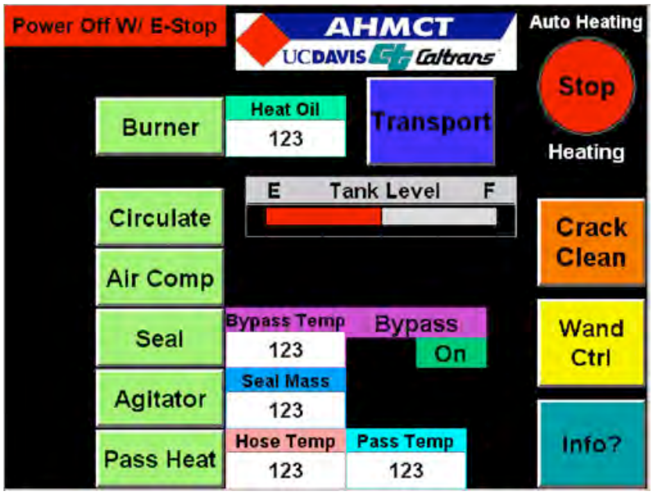

Figure 26. GUI Transport – Auto Heating Screen

5.6. Longitudinal Sealing Operation

Caltrans ordinarily transports longitudinal crack sealing machines to the worksite at full operational temperature and recirculates sealant through the sealant wand. The machine is then positioned in a spot where the operator can safely exit and walk around the vehicle to configure the Sealzall for longitudinal operation. For moving closure operations, the machine is generally positioned adjacent to an onramp. The Sealzall should be at this point configured for active sealant recirculation through the sealant wand and is maintained in this state throughout the configuration process.

To configure the Sealzall for longitudinal sealing operation, the operator needs only to deploy the longitudinal sealing carriage assembly. From the **RECIRCULATION SCREEN** (see Figure 23), the operator presses the **CARRIAGE BUTTON** and the **CARRIAGE CONTROL SCREEN** appears. The carriage when centered tucks up under the front bumper basket so it is out of the way when not in use and for transport. The operator selects the **LEFT/RIGHT BUTTON** (see Figure 27) depending on which side of the vehicle the sealing operation is to be conducted, and the carriage automatically extends to position and stops. The **CARRIAGE POSITION** indicator confirms the minimum extension position has been reached so the sealing wand can be attached (see Figure 28). Pressing the **RETURN BUTTON** switches the GUI back to the **RECIRCULATION SCREEN**. With the sealant re-circulating and the carriage extended, this is the ideal machine holding position just before pulling into the lane to start sealing.

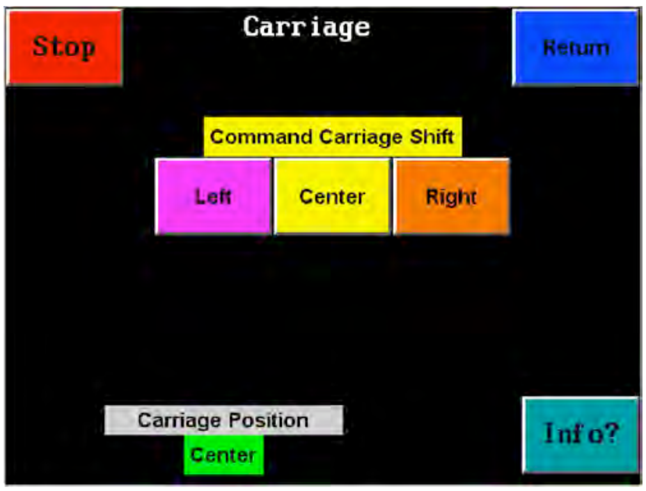

Figure 27. GUI Carriage Control Screen

Figure 28. Longitudinal Carriage Min Extend

All that is required to begin the sealing operation from the holding position is to mount the sealing wand to the carriage and switch the GUI over to longitudinal control. On the GUI the operator presses the **LONGITUDINAL BUTTON** and the **LONGITUDINAL SCREEN** is displayed providing access to the necessary longitudinal sealing controls (see Figure 29). Switching to the **LONGITUDINAL SCREEN** engages the shoe lift control in the default **UP** position and ceases wand recirculation. The operator must then remove the sealant wand from the recirculation cradle and mount it on the carriage (see Figure 30) with the extra length of hose coiled in the bumper basket.

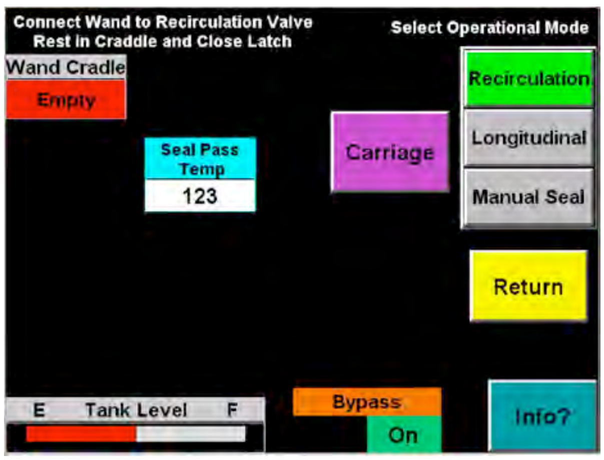

Figure 29. GUI Recirculation Screen W/O Wand


Figure 30. Wand Longitudinal Mounting

A sensor monitors when the sealant wand is attached to the longitudinal mounting and changes the carriage controls available to the operator. When the wand is mounted on the carriage, the GUI **CARRIAGE CONTROL SCREEN** changes to display only the **CARRIAGE ADJUSTMENT BUTTONS** (see Figure 31). The operator then adjusts the carriage laterally at any point as necessary. The **CARRIAGE BUTTON** is always available throughout the many longitudinal control screens so the wand can adjust out for better operator visibility or adjust in close to avoid obstacles on the fly.

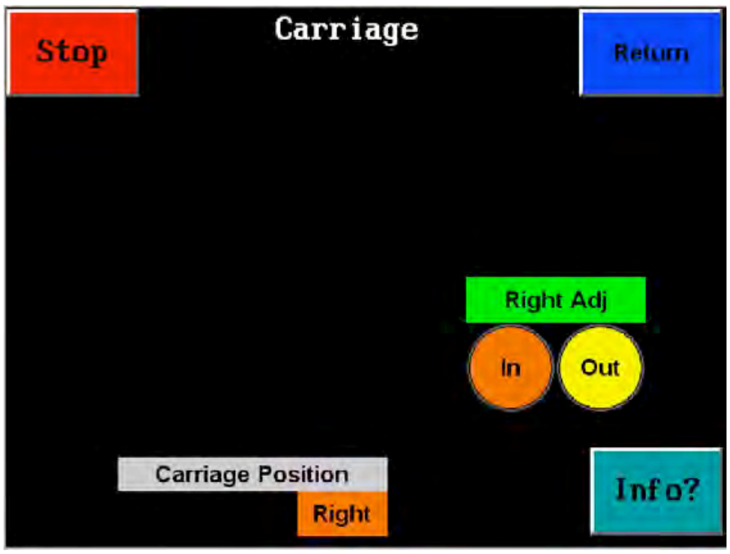

Figure 31. GUI Carriage Lateral Adjustment Screen

To begin longitudinal sealing the operator presses the **LONGITUDINAL BUTTON** (see Figure 29) and the GUI changes to display the longitudinal sealing process controls. The operator can select on this screen to engage the detack spray and crack cleaning accessories, which will then be automatically controlled with respect to the longitudinal sealing process. Then, the **SEAL OPS BUTTON** is pressed to begin the longitudinal sealing process.

A handheld, wireless remote controller is the most convenient method for the operator to control the longitudinal sealing process. Pressing the *BUTTON* representations on the GUI performs the same function as the buttons on the remote, but compels the operator to look at the

GUI. The conventional, longitudinal sealing operator posture is an arm resting on the door, elbow out the open window and grasping the handheld controller. The inside arm steers the vehicle, and the driver's head is shifted close to the window providing a common line of sight straight ahead and a sealing shoe view with a glance. It is recommended to find a comfortable head position that does not require head movement when shifting focus between the road ahead and the sealing shoe to reduce neck strain.

The functionality of each handheld remote button will change with respect to the current sealing process operational phase. The active buttons and their current functions are clearly shown with a representation on the GUI display on all three **SEAL OPS SCREENS**. The vehicle is positioned such that the lifted sealing shoe is a few feet ahead and approximately inline to the start of the crack to seal.

The phases of longitudinal seal ops control begin with the **SHOE DROP SCREEN** displayed on the GUI (see Figure 32). The operator begins by dropping the seal shoe to the road surface with the push of the *DROP HEAD* button either on the handheld remote or on the GUI. With the shoe down, the vehicle is then steered while rolling forward to center the crack in the shoe and stopped at the beginning of the crack to seal (see Figure 33).

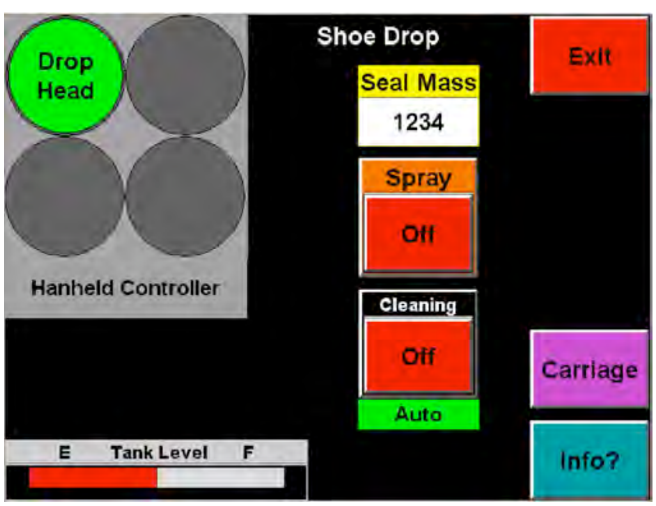

Figure 32. GUI Seal Ops – Shoe Drop Screen

The GUI displays the **SEAL START/LIFT SCREEN** where two possible subsequent actions can be taken. Pressing the *SHOE LIFT* button will lift the sealing shoe and return the GUI to the **SHOE DROP SCREEN** (see Figure 34), or pressing *SEAL ON* will start the sealant flowing into the shoe. The operator waits until the shoe half fills with sealant and then starts to move the vehicle forward while steering the shoe along the longitudinal crack.

Figure 33. Longitudinal Sealing Shoe

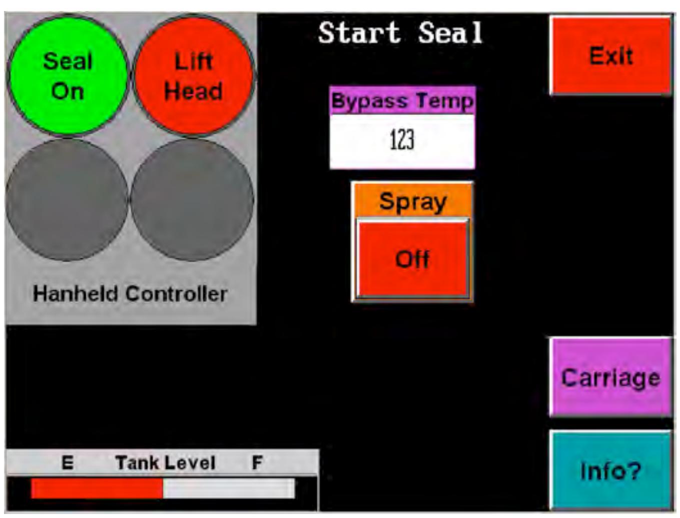

Figure 34. GUI Seal Ops – Seal Start/Lift Screen

The driver varies vehicle speed as necessary to maintain the half filled state of the sealing shoe, which is directly influenced by changing crack size. The resulting nominal longitudinal speed, typically between 2-5 mph, can be increased or decreased by adjusting the sealant flow rate. The desired, nominal crack sealing speed is generally limited to how fast the driver can drive while accurately guiding the shoe along the crack. Contributing factors that affect longitudinal sealing speed include driver skill, crack straightness, crack size uniformity and proximity of raised pavement markers.

The **SEAL FLOW SCREEN** is displayed on the GUI (see Figure 35) during the active sealing process. The **SEAL FLOW INDICATOR** displays the current rate and the operator can preset incremental adjustments by pressing the *LESS FLOW* and *MORE FLOW* buttons on the handheld controller. The adjusted flow rate becomes the saved default setting and used each time the sealant flow is restarted. The **FWD/REV BUTTON** is also available on the GUI to allow the operator to reverse seal flow should it become necessary in rare occasions. The operator can suspend seal flow by pressing the *SEAL OFF* button, and the GUI changes to the **SEAL START/LIFT SCREEN** (see Figure 34)**.** This same button then becomes the *SEAL ON* button, which restarts the seal flow. This way the operator can toggle the sealant flow on and off by repeatedly pressing this same button, which is yet another way to meter sealant flow.

With the sealant flow off and the **SEAL START/LIFT SCREEN** on the GUI, pressing the *LIFT HEAD* button will lift the sealing shoe. It is recommended to run out the sealant in the shoe and then lift the shoe as the vehicle is moving to avoid leaving behind a sealant puddle. With the sealing shoe lifted, the initial **SHOE DROP SCREEN** (see Figure 32) is displayed on the GUI, and the process has come full circle back to the starting position. Pressing the **EXIT BUTTON** will return the GUI to the **RECIRCULATION SCREEN**.

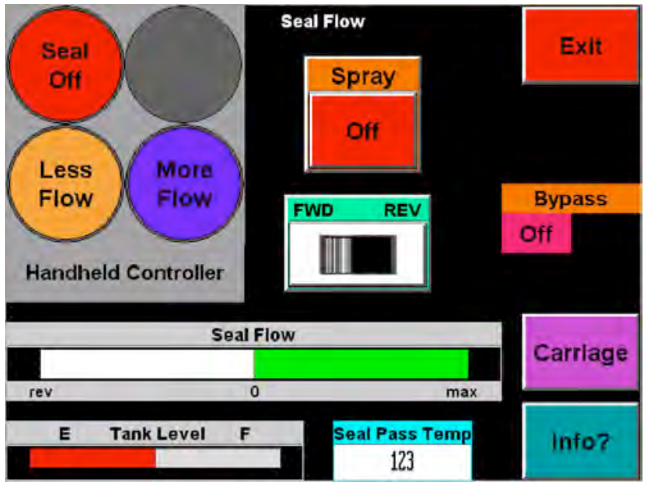

Figure 35. GUI Seal Ops – Seal Flow Screen

5.7. In-Lane Sealing Operation

The defining Sealzall feature is the incorporation of a sealant hose and wand assembly that extends machine capabilities beyond that of longitudinal only sealing to support the sealing of any type of highway crack. The Sealzall in-lane sealing feature is not automated and requires a worker to stand on the pavement and physically apply the sealant to the cracks. Therefore, for optimum efficiency the continuous longitudinal operation should be utilized to seal as many longitudinal cracks as possible first and then followed with the in-lane sealing operation to seal the remaining cracks manually.

The manual sealing operation requires a fixed lane closure unlike the longitudinal sealing operation, which can operate in either a moving or a fixed closure. The Sealzall faces in the normal direction of traffic and from the end of the closure backs up in the lane as sealing progresses. Since manual sealing takes place in the front of the vehicle, the driver has a direct and up-close view of the workers during the sealing process.

From the Sealzall recirculation stage, the **MANUAL SEAL BUTTON** is pressed changing the GUI to the **MANUAL SEAL SCREEN** (see Figure 36), and the sealant wand is removed from the recirculation cradle. The order of these steps is interchangeable, but the recirculation sealant flow should be terminated before removing the wand from the cradle. The cradle latch switch will sense when the wand is removed and stop seal flow as a safety backup precaution. A hose support boom is stowed on the rear of the chassis, which can be dropped into a basket holder mounted on the front bumper to support the sealant hose off the pavement (see Figure 37).

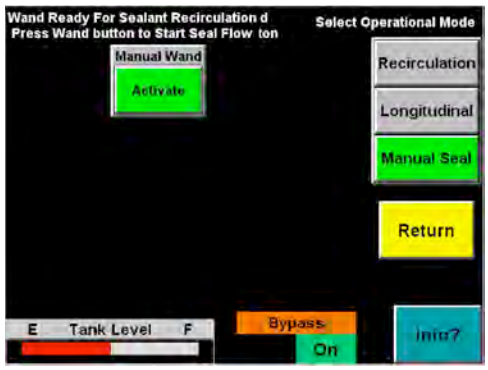

Figure 36. GUI Seal Ops – Shoe Drop Screen


Figure 37. Manual Sealing Hose and Support Boom

A sealing disk accessory mounts to the end of the sealing wand via a quick connector attachment to produce an overband appearance, thus eliminating the need for a secondary squeegee. An adjustable shoulder strap is provided that clips to the wand to comfortably support the weight. The driver needs to press the **ACTIVATE BUTTON** on the GUI in the cab to activate the control buttons on the sealant wand thereby transferring seal flow control over to the operator holding the wand. Some additional features appear on the GUI display, which indicates seal flow rate and direction as well as showing when the wand control buttons are pressed (see Figure 38).

The worker must hold down the wand *X3* button (see Figure 39) to get sealant flowing from the wand. The wand flow control functions as a common "deadman" style switch, which prevents sealant flow should the wand be released. The sealant flow can be increased by predefined increments only as the sealant is flowing by holding down the *X4* button. To decrease the sealant flow, the *X4* button must be pressed and held for 2 seconds and released for 2 seconds repeatedly until the sealant flow slows as desired. The adjusted seal flow rate becomes the saved default flow rate.

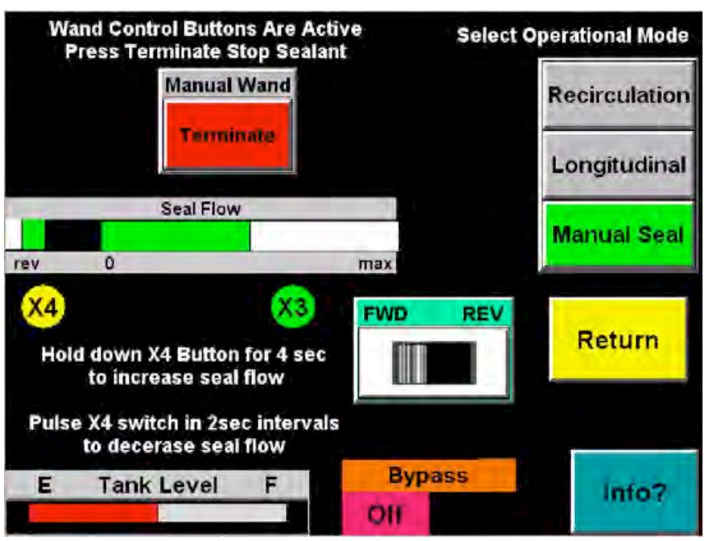

Figure 38. GUI Seal Ops – Seal Start/Lift Screen

For breaks in sealing lasting more than a few minutes, the sealant wand should be returned to the recirculation cradle and the recirculation cycle initiated. Circulating hot sealant will maintain the sealing hose at optimum application temperature. At the end of the operation the sealing hose and wand should be coiled in the bumper basket and strapped down for transport.

5.8. General Maintenance

For daily operation, the Sealzall system consumes gasoline and propane, and these tanks contain only a day's operational capacity. So, both of these tanks should be filled prior to the beginning of the day's operation. Other operational fluids that should be checked daily include hydraulic oil tank level, air compressor oil reservoir, auxiliary engine oil level and sealant kettle heat transfer oil level.

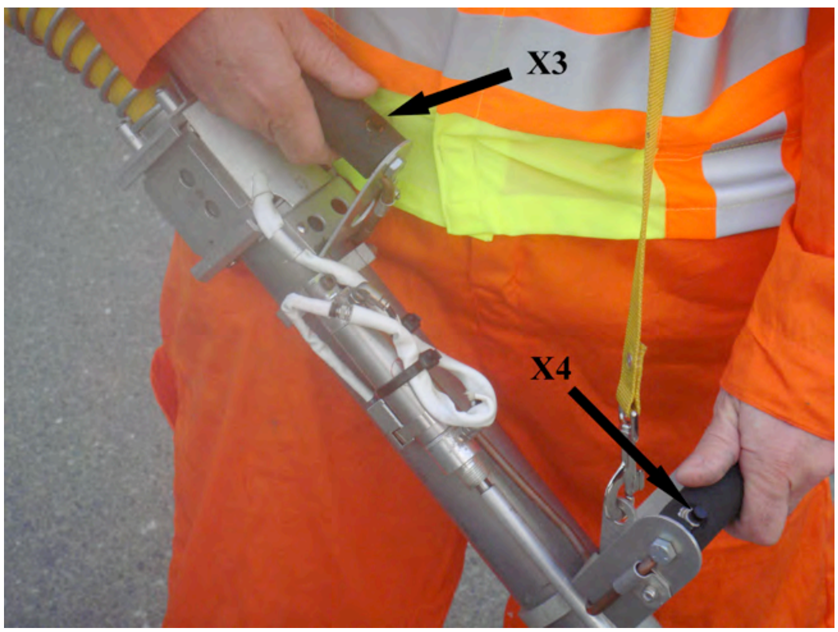

Figure 39. Sealing Wand Controls

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1. Bennett, D.A. and Velinsky, S.A., "Development of the Transfer Tank Longitudinal Sealer," Final Report of Caltrans IA 65A0049, Task Order: 02-10, AHMCT Research Report #UCD-ARR-05-12-31-01, 2005, 68 pp.