Design of a Hoist for the Removal and Replacement of Horizontal Semiconductor Wafer Furnace Heater Cores at the Hewlett-Packard, Corvallis, Oregon Site

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ABSTRACT

Hewlett-Packard lifting guidelines and analysis using common ergonomic evaluation tools indicated that manual replacement of heater cores in horizontal furnaces was unacceptable and engineering intervention was required. The design was guided by a number of physical constraints and worker requirements, for example, weight of and access to the heater cores, accessibility to maintenance bays, and the need for elevated work platforms. The cooperative risk reduction effort took a year and involved maintenance technicians, HP's ergonomics engineer, and engineers from the hoist vendor. The final design employs a strap and roller end-effector with a two-arm articulated manipulator mounted to a counterweighted ball screw type vertical hoist. The hoist has the ability to hold the heater core securely while allowing technicians to place it in position for installation. It is also compatible with the requirements of a Class 100 clean room, is powered by an internal power supply with integral charging unit, and has casters which allow for mobility. Using the hoist, the technicians can now perform the replacement procedure without manual lifting of the cores or exceeding standards for lifting and pushing forces. A follow-up survey indicated a high level of satisfaction by the users of the new system.

PURPOSE AND TARGET AUDIENCE

This paper should familiarize the reader with the problem that generated the need for this project, the constraints that guided the design and fine-tuning the process once the prototype was built. Also included are the details of the role of the Oregon-OSHA Worksite Redesign Program, describing how that program was used to assist with the project. The paper is intended to assist the ergonomist in breaking into the process of designing lifting aids.

INTRODUCTION

Maintenance Technicians in the Furnace area of Corvallis HP integrated circuit factory recognized the undesirable nature of the task of replacing heater cores in horizontal furnaces long before this project began. They had been unsuccessful in finding a commercially available solution to the problem. In June of 1998, a maintenance technician at the Hewlett-Packard Corvallis plant visited on-site medical personnel complaining of shoulder pain. Questions by the nurse as to the maximum weights lifted in the course of typical maintenance tasks revealed a task that the nurse recognized to be far outside lifting standards established by the Environmental Health and Safety (EHS) department at the plant. A subsequent meeting between the nurse, the technician management staff, and engineers determined that the task of manually replacing the heater cores in the horizontal furnaces was too dangerous to be continued, and therefore, the task was "suspended" until intervention was in place. Given the potential impact on production as a result of not performing this maintenance task, an immediate design effort was initiated.

ERGONOMIC ASSESSMENT

The heater cores in the horizontal furnaces weigh 210 pounds each (95.25 kg), are 71.5 inches (181.6 cm) long and 16 inches (40.6 cm) in diameter. They are arranged in a vertical stack of four furnaces with the height of the core centers ranging from 32 inches (81.3 cm) to 86 inches (218.4 cm) above the floor. On average, one to two tube replacements occur per month. In this case, frequency of the lift was not a factor, in the sense commonly used in typical ergonomic evaluations.

Prior to the start of this project, average height and shorter workers were required to use scaffolding intended for maintenance of other tools to support one leg while standing on the frame of the tool with the other (see Photo 1). Technicians removing the core with such precarious footing were exposed to the hazards of being crushed by a falling heater core and falling into sharp sheet metal protective shrouding or possibly contacting electrical lines. They also risked injury from lifting such a heavy, large and awkwardly shaped object over a large vertical and horizontal range of motion. The typical (informal) manner of removing and replacing the two highest cores was to get the tallest technicians in the fabrication facility (hereafter referred to as the "fab"), who could lift the cores out without use of scaffolding. Shortly before the reported injury referred to above, the tall technicians had transferred to another site.

EVALUATION

Hewlett-Packard Company guidelines at the Corvallis facility limit the weight that a technician can lift to 50 pounds under ideal conditions, defined as low frequency (less often than once per hour), close to the body, between elbow and shoulder

Photo 1
Beginning core disassembly

height. Considering these guidelines, even if the heater cores could be held in an "ideal" position with good handholds throughout the replacement procedure (which it cannot, as is evident from Photo 1), and the load could be equally shared, it would still require five technicians to perform the task. Ergonomic and safety considerations including footing, lifting postures, distances to move the core, etc., caused estimates of effective safe team size for the task to grow to between 8 and 10 technicians. Logistically, this was not possible, even if there had been suitable workarounds for these issues.

Two ergonomic evaluation tools were used to estimate the risk of the task. Assumptions for the analysis were that of a 180 pound male (the average team member weight and gender) lifting ½ the total weight of the core, as would nominally be the case in a two-person lift. A NIOSH revised lifting equation analysis of the task resulted in a recommended weight limit (RWL) at the initial position (the core in the furnace) of 10.5 lb. and at the destination (on a common cart in the fab) of 17.8 lb. The lifting index (LI) at the origin was, therefore, about

10 (that is, 10 times the recommended weight limit for the task) and near 6 at the destination, obviously far from an appropriate lift. Use of the University of Utah Simplified Shoulder Moment Estimation tool calculated the maximum available shoulder moment for a 183-lb. male and the postures necessary for this task at 743 in-lbf. (inch-pounds-force, a unit for torque or moment). The actual shoulder moment (worst case) generated by this task was 1420 in-lbf. resulting in a percent of maximum shoulder strength of 191%. These values are summarized below in Table 1. Several of the procedures informally adopted by the technicians to complete the task were also outside established safety standards, for example, maintaining insecure footing, stepping onto adjacent frame members from an elevated work platform, lifting above the shoulder, etc.

Table 1 Lifting equation and shoulder moment estimation tool results

Table 1		
NIOSH revised lifting equation results:		
Value name	Origin	Destination
RWL	10.5 lb.	17.8 lb.
LI	10 times the origin RWL	6 times the destination RWL
University of Utah Simplified Shoulder Moment Estimation tool results:		
Maximum available shoulder moment	743 in-lbf	
Worst case moment generated by task (calculated actual)	1420 in-lbf	
% of maximum available shoulder moment	191%	

DESIGN CONSTRAINTS

Based upon a variety of factors (e.g., furnace design, furnace layout in the fabrication facility, cleanliness issues, etc.), a number of design constraints were determined. The cores rest on a cradle composed of two small wedge-shaped steel tubes that run parallel to the core axis. The cradles contact either side of the core bottom, and run to within 5 inches of either end (see figure 1).

These 5-inch long unsupported ends of the cores are the only places to access the core with an end-effector. In this area, there is too little clearance (the cores are separated vertically by just over 1 inch) to access the core easily and safely with a conventional fork-type lifting device. Therefore, extreme low profile of the attachment component that was to fit between the cores was a requirement. An additional constraint was that the core be solidly attached to the lifting mechanism during transport and placement. This requirement stemmed primarily from the difficulty in manually guiding the core at the height of the two upper core bays and the potentially serious consequences of dropping a core (for example, off the end of a “fork lift” type device).

When placed, the core must be rotationally oriented about its longitudinal axis in the core bay to align the electrical shielding on the side of the core such that it will not interfere with the placement of the furnace framework upon reassembly. The horizontal opening of the enclosure into the core bay, in some cases, is narrower than the length of the core, requiring that the core be placed in the bay one end at a time. Also, a protruding enclosure at the floor level houses temperature control electronics and restricts usable approach space in the maintenance access area.

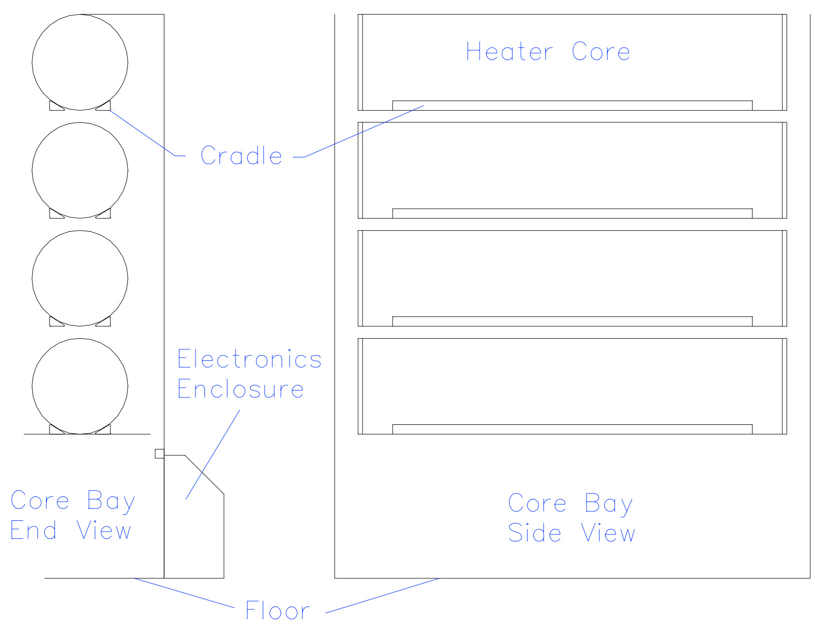

Figure 1
End and Side view schematic of the heater core bay

Additional constraints result from the particular construction and environmental requirements of the cleanroom. An overhead HEPA-filtration system that completely covers the ceiling eliminated the possibility of attaching an upper jib crane pivot or trolley. A suspended metal floor positioned about a foot over a perforated structural concrete (“waffle”) floor makes cantilever attachment of a crane to the floor very difficult. Two of the furnace maintenance bays (where the cores reside) face each other and are located on a dedicated isle used to move equipment into and out of the fab, making placement of a permanent jib impossible. These constraints eliminated all but a portable system.

The combined impact of these constraints dictated that the intervention method allow the core to be completely supported by non-manual means throughout its travel from the loading dock and into the fab. In addition, it must be mobile in five degrees of freedom (three translational, two rotational), portable, and keep all forces applied by the technicians within appropriate values. With

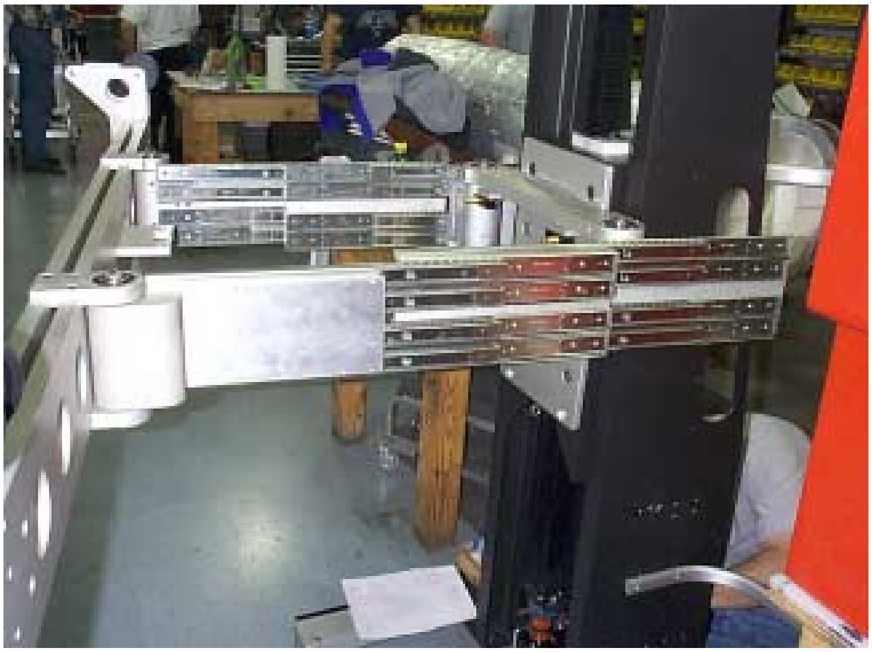

Photo 2
First arm extension concept

these formidable design requirements, there was no off-the-shelf equipment available which could accomplish them.

DESIGN PROCESS

When an extensive search for off-the-shelf portable hoists failed, a search began for companies that construct custom hoists. Alum-A-Lift of Winston, Georgia was selected. Design parameters and constraints were sent to the vendor and their engineer visited the Corvallis HP site for measuring and documenting the problem task and constraints. The cooperative design effort required several iterations and the prototype required one major redesign/rebuild. The prototype was initially constructed using a concept that employed several stacked industrial drawer slides (see Photo 2). This design failed tests at the vendor's facility when HP's inspectors could not move the core through the required range of motion within the specified user input force requirements. Specifically, the drawer slides were unable to withstand the bending loads placed on the arms without severe binding. HP inspectors estimated a required two hundred pounds of user input force to extend the arms the final six inches of travel.

HP's project engineer proposed the original concept of dual articulated arms and the second design iteration returned to this design. However, maintenance aisle access constraints limited the width of the hoist to 36 inches. This resulted in a relatively narrow hoist base. The design required some means to address the problem of excessive side swing of the manipulator. With a heater core in place and the small footprint, there was a risk of tipping the hoist over to the side. Vendor engineers were able to install stops that effectively limited the arm travel while still allowing full extension of the manipulator. In this configuration, it is possible to move the core to the limits of motion in all required degrees of freedom with less than 5 pounds of user input force while maintaining suitable stability of the hoist (see Photo 3).

Figure 3
Final configuration of the hoist manipulator

To attach the core to the manipulator, an attachment system was designed that uses two rollers and two pulleys on each end of a 5 ½ foot long end effector with a webbing strap which girds the heater core (see Photo 4).

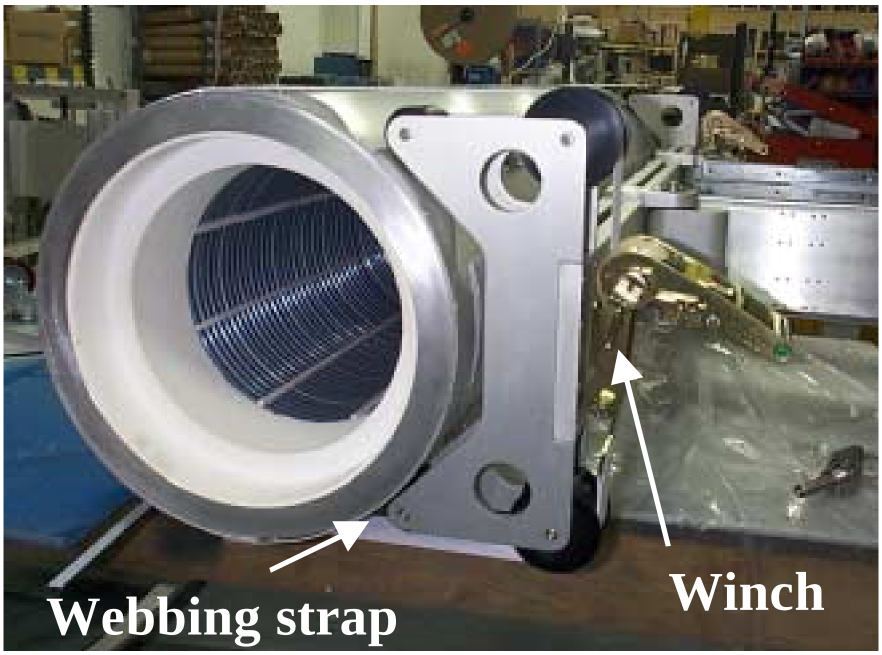

Photo 4
End effector/core attachment detail

ACCESSORIES

To enhance the stability of the hoist when in position to transfer a core to or from the core bay, brakes were requested from the vendor. After several design iterations of the brake, an outrigger mounted, foot actuated and released brake was employed, which works very well.

Two inches of clearance below the furnace and electronics enclosure on all of the furnace stacks allows the use of outriggers that extend under the enclosure. This design prevents the possibility of the hoist tipping forward in the event that an operator inadvertently attempts to lift the core into the framework above while still in its bay. The extension of the outriggers is electrically interlocked with the end effector. The end effector is equipped with a mechanically latched and electrically unlatched catch that holds it in the fully retracted position when stowed. The unlatch function is disabled if the outriggers are not locked in their fully extended positions. If the outriggers are unlocked from their fully extended positions before the end effector is latched in its fully retracted position, a loud alarm horn sounds. This system is very simple but prevents the technician from unknowingly getting into a dangerous tipping situation (see Photo 5).

With the hoist in place for extraction of a heater core, there was no space for a conventional scaffolding or elevated work platform to fit into the bay. Thus, a dedicated platform that could reach over the electronics enclosure was needed. The platform had to be easily moved and set up, easy to use without any danger of tipping, require very little floor space, and provide a cleanroom compatible surface with secure footing. Two platforms are required, one on each side of the hoist. In the final design, handles on each side of the platforms permitted easily pulling them on their wheels. A ½ inch stainless steel plate at the base provides enough counter-mass to keep the platform from tipping during transport and when first stepped onto (see Photo 6).

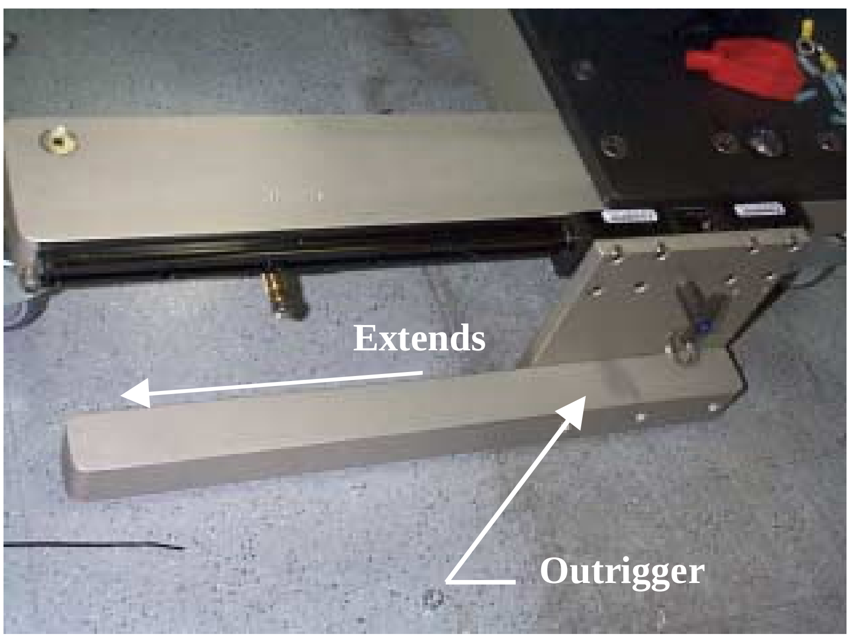

Photo 5
Hoist outrigger detail

POST-PROJECT EVALUATION

The project engineer worked closely with technicians who use the hoist to evaluate the hoist system when first used to replace heater cores. Although there were several minor issues that resulted in changes, such as reorienting handles used to move the end effector, the hoist worked well from the first use. Technicians like the ease with which the cores can be moved and the control that can be exercised when placing the cores. Although the recommended procedure is to have two technicians replace a core, a single technician of any stature can replace the core faster than a crew of four before the hoist was in place, and with much greater control and less jostling of the other process tubes in the stack. This results in less downtime and increased production. Although the benefits to production are clear, the major advantage of the project is the reduced risk to workers. The hoist met or exceeded every design goal of the project with no disadvantages. A survey of the technician's group after the hoist had been in place for several months indicated a high level of satisfaction with the final project resolution.

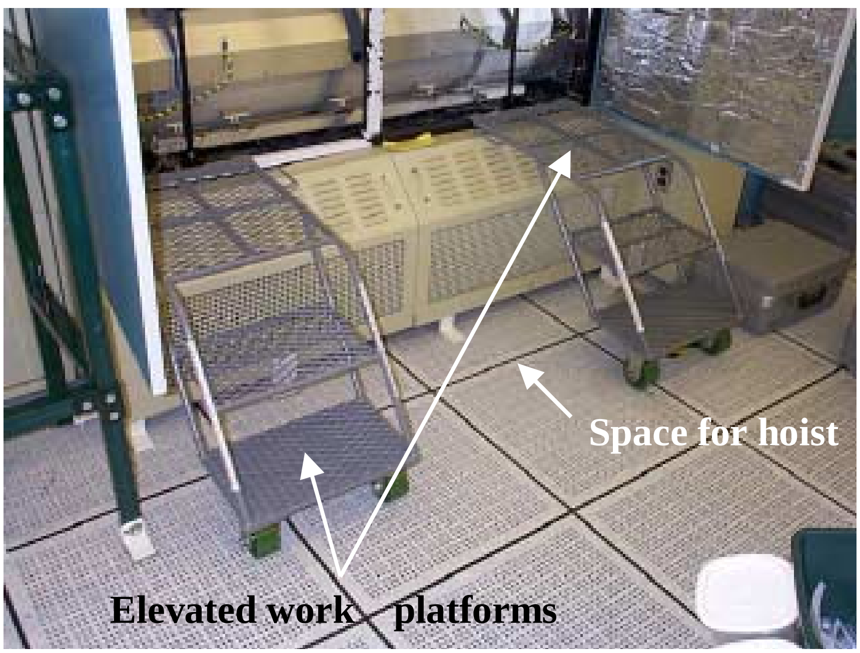

Photo 6
Elevated work platforms in place over electronics housings

ROLE OF THE WORKSITE REDESIGN PROGRAM (WRP)

Near the inception of this project, the project engineer learned of a progressive program through the Oregon division of the Occupational Safety and Health Administration. This program provides funds for the development of engineering resolutions to workplace problems of an ergonomic nature for which no off-the-shelf solution exists. A provision of the program is that the results of the solution be disseminated to industry, especially to industry within the State of Oregon so that other workers may benefit from the project. Hewlett-Packard's policy on the release of information concerning safety and ergonomic improvements is consistent with this provision.

The application process is detailed, but straightforward and the grant requires periodic reports. Up to 90% of the cost of the design/prototyping portion of the project is paid by the WRP to a maximum of $150,000. The cost of this project was about half that amount. Additional grant money is available to implement the solution if more units (hoists) are needed at HP's facilities. This grant is also available to other companies in the industry (must also be within Oregon) that could use this type of hoist. A number of avenues were pursued at the conclusion of the project to make other companies aware of the improvement, but the most productive thus far has been to contact the sales force of the heater core supplier. The primary benefit from the project engineer's perspective is that the project was much less at the mercy of budgetary constraints because of the grant monies and could, therefore, be conducted with greater flexibility to thoroughly address all aspects of the issue. The end result was a completely successful project with no unresolved problems or gaps in the solution.

SUMMARY

Technicians recognized the task of removing and replacing heater cores in the horizontal furnaces to be an undesirable lifting situation long before this project began. Several attempts had been made to find a commercially available solution but were unsuccessful. When a possible connection between this task and an injury was made, the increased urgency drove the project to a rapid resolution. The division Ergonomics Design Engineer at HP recognized the need for a custom solution and Alum-A-Lift was selected as the most viable vendor to provide the hoist. The OR-OSHA Worksite Redesign Program was utilized to provide development funding for the project that began in the spring of 1998. Several design iterations later, the project was concluded in the spring of 1999. The hoist system eliminates the risks of the previous task and substantially decreases the time required to replace a heater core. Maintenance technicians were heavily involved in the design as it progressed, and (perhaps as a result) have expressed great satisfaction with the results.