Design and Development of a Tugger Cart for Android Industries

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Abstract

There are many hazards associated with the industrial powder coating process. Powder coating operations require the use of curing ovens at high temperatures to cure the parts. The high temperature environment may expose employees to higher risks which may compromise safety. The objective of this project was to develop a system to eliminate the need for an employee to enter the oven to retrieve curing racks. The previous system wasted large amounts of energy due to repeated heating and cooling of the oven to allow employees to enter the oven.

A remotely controlled tugger cart would eliminate the need for cool down resulting in an increase in productivity while reducing employee risk. The cart was designed to travel under the racks to move the rack out of the oven. Critical performance requirements included safety, reliability, ease of operation and long battery life. The cart design used a modular concept that is versatile for use in different applications. Additional tests were required to test for the robustness of radio communication to ensure reliability. The proposed cart also had to be cost effective compared to similar systems available in the market.

Introduction

"From the first digitally operated and programmable robot, the 'Unimate', installed in 1961 to lift hot pieces of metal from a die casting machine and stack them in GM up to now, robots have become essential part of modern industries."[1] There are many hazards associated with the industrial powder coating process. Powder coating operations require the use of curing ovens that operate at high temperatures to allow the paint to fuse to the parts. Along with these high temperatures come risks for the employees that operate the oven. Employees previously had to enter a curing oven that was at a temperature of 450 °F to remove the racks that the powder coated parts hung on. The high temperatures inside the oven create oxygen deficient spaces, which may result in death if the employee is not properly protected. The proposed project was to develop a remotely operated cart that would remove the racks from the curing oven. This cart was specifically designed for the custom powder coating racks in use at the Android Industries-Flint campus. Android Flint provided material, resources and equipment to develop this product. There are currently no tugger carts in the marketplace that have clamps designed to remove racks from a curing oven. The goal of the project was to design a cart to remove the racks from the oven efficiently and safely with a custom clamp for the racks at Android Industries.

Literature review

Many safety hazards accompany the use of the curing oven in the powder coating process. In 2010, a man died while working in a curing oven. "Liverpool Crown Court heard that because there was no alarm. Mr. Catterall tried to escape using a crowbar but because of the noisy working environment no one heard his cries for help."[2] Currently Android Industries requires an employee to enter the curing oven to remove parts.

To prevent a catastrophic event from happening at Android a tugger cart was proposed. An autonomously guided vehicle (AGV) was investigated alongside a remote controlled vehicle. Crefrom Intelligent AGV Systems produces a tugger cart; the NSB BST Tugger has a low profile design and uses a magnetic tape path for its guidance. The NSB model has an eight-bit optical communications device for remote control and starting. It also features an electromechanical emergency and parking brake, a non-contact programmable laser bumper and e-stop with 8-view sets plus other standard safety features including audible warning and flashing light.[5] DJI products manufactures a remote controlled tugger cart called the Wagon Caddy HD.[3] Patent number 7497448 is a flatbed cart similar to the teams design without the clamp feature needed to remove the rack from the oven.[4] Another patent number US 8167323 B1 explains how handcarts, hand trucks, and similar manually operated conveyances have been known and used for a considerable period of time to facilitate the transport of limited loads over limited distances and terrain.[10]

The team chose to use an AGM battery. "From a user's point of view, for a low cost UPS battery with an expected life of 5 to 10 years, the AGM battery is a good choice. For applications where life times exceeding 10 years are expected, GEL batteries are the better choice."[8] AGM batteries are also the standard battery used in the plant.

Methods

Concepts

Design and develop a tugger cart that can be remotely controlled by an operator. Since the cart would be operating in extreme temperatures, it needed to have a protective coating/insulation to resist the heat of oven. The cart would latch onto the front end of the rack and proceed to move it. It would be able to pull the racks into or out of the oven depending on the operation being done. Something that was important to keep in mind for all concepts was the ability to take high amounts of heat over time especially for the electrical components. According to Chen and Nelson "a key consideration in the packaging of the devices is that the bonds between the different materials are capable of sustaining the mechanical and thermal stresses over the service life of the device."[9]

Automatic guided vehicles (AGV) are attractive because of their labor savings. The design team chose not to do one because a limited drive path is one of their disadvantages (Arkin

1990). There is approximately one and a half hours of down time between runs through the curing oven. Therefore, an expensive AGV will not have a significantly long return on investment (ROI). In the future, Android Industries may choose to adapt this design for use as an AGV when the powder coating process has fewer path options and more ovens are added. Safety is a higher priority than efficiency in this design.

Concept One

Design and develop a cart that is capable of traveling inside the oven and latch onto the rack, then proceed to pull the rack out of the oven. The first variation considered was to incorporate four Mecanum style wheels into the design to allow the car to have full translational movement. "Mecanum wheels are used when omnidirectional movability of a vehicle is desired. That means that the vehicle can move along a prescribed path and at the same time rotate arbitrarily around its center. A Mecanum wheel consists of a set of rolls arranged around the wheel axis."[7] All four wheels would be driven independently due to the Mecanum's design. This concept has the most maneuverability but its advantages are lost when multiple tugger carts are needed due to the higher cost to manufacture the wheels.

Concept Two

Design and develop a cart that is capable of traveling underneath the racks and latch onto them, then proceed to pull the rack out of the oven. The second variation considered was to use standard wheels in place of the Mecanum wheels. It would have two drive wheels at the front of the cart and two casters at the rear. By using standard wheels, the cart would lose the side-to-side translational freedom of movement due to the elimination of the hybrid wheels. Standard wheels would make the cart cheaper to produce but would lose some of its maneuverability.

There were two proposed methods for the charging of the carts batteries. The first would be a floor-charging pad that the cart would park on top of to charge the batteries. The second would be a standard wall plug option that would allow it to be charged at the nearest 110V outlet. The wall plug charging option would rely on the operator to plug in the cart when it is not in use. The floor charger would allow for future automation of the carts. Therefore, a lot of thought has gone into what batteries will be used as well as the method for charging.

Concept Three

An automated guided vehicle (AGV) was another option. The AGV would have be programmed to follow a colored path through the plant or a metal tape like BST model produced by Creform.[5] It would use the same clamping mechanism and designs. The main difference would be the elimination of the transmitter and receiver. It would have had laser sensors to ensure that it was in correct orientation for charging.

Final Concept

Concept two was chosen for its simplicity and low cost. There will most likely be many more of these carts made for the plant and keeping the cost down is a high priority. The Mecanum wheels have high fabrication costs associated with them because of the custom sizing needed. This eliminated concept one from consideration. Concept three had high cost associated with it as well because of the need for extra sensors. The plant union and the elimination of jobs was another issue with the AGV concept. Flexibility is a concern as Android goes forward. The ability to adapt the clamp so that it can move carts of different sizes will become important as cart sizes change in the future. "This flexibility heightens a company's potential responsiveness to competitive and/or market changes."[4] Competitive forces required the design to prioritize flexibility highly. The final concept required a customized clamp in order to grasp the rack and remove it from the oven. Design of the clamp was the most critical and time-consuming part of the project.

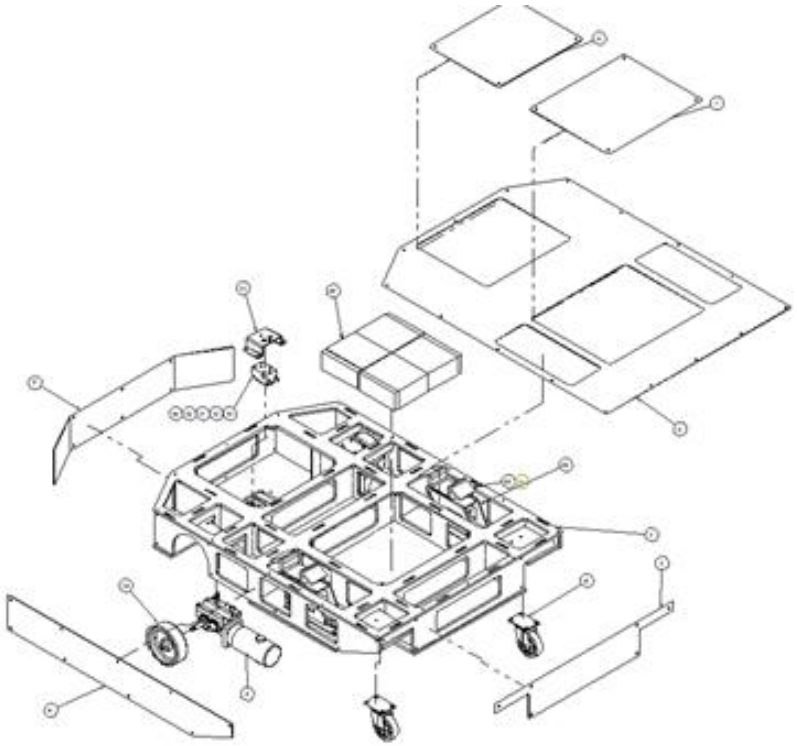

Figure 1: Assembly drawing of the Tugger Cart Assembly

Design tools/processes

During the design process Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD) were used to evaluate design concepts for their robustness. While determining the possible failure modes both a Process Failure Mode and Effect Analysis (PFMEA) and a Design Failure Mode and Effect Analysis (DFMEA) were utilized to capture and correct any potential failures before they ever occurred. Design for Manufacture (DFM) and Design for

Assembly (DFA) were used to optimize the final design for ease of manufacturability and assembly. By optimizing the design for manufacturability, it reduced the number of unique features and time for machining. By optimizing the design for assembly, it reduced the overall assembly time and assembly error by minimizing the number of parts and possible alternate orientations. A House of Quality (HOQ) was used to define the relationship between the customer wants and the engineering specifications. By utilizing the HOQ, the team was able to keep the needs and wants of Android in perspective throughout the design process and were able to meet or exceed all requirements. Throughout the course of the project Gantt charts were used to track all aspects of the progress and to make sure that the project would be delivered on time. A function structure was developed to aid in the design and operation process as well as the dissemination of functionality and interactions between parts to the customer. The Analytic Hierarchy Process (AHP) aided in the decision making process between initial concepts by weighing the strengths and weaknesses of each.

Results

The tugger cart took four minutes to remove the rack from the oven. After fifty cycles of the clamp latching onto the rack there was no noticeable wear. The microcontroller and battery were not affected by the high temperatures and the thermocouple showed temperatures below the 150˚F needed. If the cart is used to only remove racks from the oven it will only need to be charged twice a day. As the operators get used to the controls, the amount of time that will be required to complete the task will go down. The cart can be remote controlled by over 50ft before it would require a signal booster further improving the safety of the workers. The cart survived the weight load of 3000 lbs. with only a minimum of 35 lbs. of force which had been estimated during the design process. Testing for maneuverability the team discovered that the cart could navigate through cones spaced 10' apart. It took 1.5 hours to completely discharge the batteries under a full load. Clamping realiabilty was tested with 100 cycles. There was never a failure while testing the clamp.

Conclusion

Industrial ovens pose severe risks to employees. In the US, a man died in an industrial oven at a Bumble Bee factory in 2012 (OSHA). With the danger of a similar accident occurring, there was an immediate need for development of a solution for Android Industries-Flint campus. Currently, there are no accidents and the goal of the product is to eliminate risk to employees while improving production & operation. This product could be considered very cost effective compared to currently available systems on the market and/or automated conveyor systems. The cost of development and building the tugger cart was $3,150. The Omnimove is an extremely expensive AGV machine costing approximately $240,000. The cheapest tugger cart is produced by Electro Kinetic Technologies with a cost of $5,115. This tugger cart is not remote controlled however and offers a much cheaper and less adaptive hitch option instead of a clamp. If even a single life is saved by using the tugger cart, it will pay for itself.

The design team's main goal in designing this was to ensure that employees find the tugger cart easy to use. If employees had found anything cumbersome in the design, it had the potential to be thrown away or left unused. "The stability of a vehicle or mobile robot becomes crucial especially when working in the environment with the existence of humans."[6] Management at Android has worked with the team throughout the project to ensure that flaws were quickly noted and revised throughout the prototyping and manufacturing processes.

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Bibliography

1. Marzbanrad, Alireza, Jalil Sharafi, Mohammad Eghtesad, and Reza Kamali. "Design, Construction and Control of a Remotely Operated Vehicle (ROV)." Volume 7: Dynamic Systems and Control; Mechatronics and Intelligent Machines, Parts A and B 2011.

2. Robinson, Martin. "Father Burned to Death inside 280C Industrial Oven He Was Working on after He Was Locked inside and It Was Switched on by Accident by His Future SON-IN-LAW ." Mail Online. November 20, 2014. Accessed December 9, 2015. http://www.dailymail.co.uk/news/article-2842536/Father-burned-death-inside-280C-industrial-oven-kayak-factory-working-colleague-accidentally-locked-switched-on.html.

3. "WagonCaddyHD Remote Controlled Powered Cart." DJ Products Inc. September 21, 2015. Accessed January 12, 2016. http://www.djproducts.com/product/military-and-dod-applications/remote-controlled-powered-cart/.

4. Brown, Edmund. Tugger Cart. US Patent 7497448, filed September 9, 2005, and issued March 15, 2007.

5. "Automated Tugger Uses Magnetic Guidepath to Transport Carts." *Product News Network*, December 9, 2010.

6. Safar, M. Juhairi Aziz, Keigo Watanabe, Shoichi Maeyama, and Isaku Nagai. 2012. Tip-over prediction for omnidirectional mobile robot. *Procedia Engineering* 41 : 1085-94.

7. Gfrerrer, A. 2008. Geometry and kinematics of the mecanum wheel. *Computer Aided Geometric Design* 25 (9) (12): 784-91.

8. Rusch, Wieland, Keith Vassallo, and Gary Hart. "Understanding the Real Differences Between GEL and AGM Batteries-You Can't Change Physics." (2007): 4-5.

9. Chen, W. T., and C. W. Nelson. 1979. 'Thermal Stress In Bonded Joints'. *IBM Journal Of Research And Development* 23 (2): 179-188. doi:10.1147/rd.232.0179.

10. Salvucci, Frank, Jr. Handcart. Salvucci Jr Frank, assignee. Patent US 8167323 B1. 1 May 2012. Print.