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DESIGN RECOMMENDATIONS FOR CONTROLLING THE JAM-CLEARING HAZARD ON RECYCLING INDUSTRY BALERS

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Abstract

Between 1986 and 2002, there were 43 fatalities in the United States to operators of recycling industry balers. Of these fatalities, 29 involved horizontal balers that were baling paper and cardboard (Taylor, 2002). Balers often become jammed while the baling process is occurring, and the only way to remove the jam is manually. This requires an employee to place a limb of their body into the jamming area and remove the material that is causing the jam. While lockout and tagout procedures reduce the risk of hazardous energy being released, they can still be easily bypassed, ignored, or forgotten. Recent efforts to reduce machine-related injury and death involve the development of a control system for these machines that automatically detects hazardous operating conditions and responds accordingly. The system is being developed at the National Institute for Occupational Safety and Health (NIOSH). This system, JamAlert, automatically terminates the power to the machine when a jam is detected. JamAlert detects a jam by observing both the strain that is experienced by the shear bar of the baler and the hydraulic pressure at which the ram is operating. The strain that is experienced by the baler shear bar when a jam is initiated was calculated in this study through laboratory testing and finite element modeling. Design recommendations are presented on how best to tune the JamAlert's operating program to most effectively control the jam-clearing hazard.

Introduction

Among workplace injuries, amputations are one of the most severe. On average, approximately 18,000 workers suffer amputations and 800 are killed using machinery each year in the US. Between 1986 and 2002, there were 43 fatalities in the United States to operators of recycling industry balers. Of these fatalities, 29 involved horizontal balers that were baling paper and cardboard (Taylor, 2002).

During the regular baling process balers often become jammed. In order to remove a jam, an employee must place a part of their body into the jammed area. Often employees perceive the jammed machinery as safe since operation has stopped. In reality the baling process will continue once the jam is removed since the machine is still energized. This is what causes injury and possibly death. While these workplace hazards can be reduced by improving workplace practices, giving adequate training, and through administrative controls, the most effective way to prevent injuries is by safeguarding the machines.

Programs are already in effect that are aimed at preventing injury from clearing jammed balers. Employers are beginning to take a more active role in educating their employees and making them aware of the hazards of their job. In order to ensure that employees follow safety procedures, the Occupational Safety and Health Administration (OSHA) has developed regulations regarding the control of hazardous energy sources and guarding machines. Since OSHA was created in 1971, occupational deaths have decreased by 62% and occupational injuries have been reduced by 42% (OSHA, 1996).

Current OSHA regulations are not specific for balers, but general regulations can be applied to situations encountered when using a baler. One important standard addresses the control of hazardous energy (29 CFR 1910.147). When servicing or maintenance of

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health machinery is required, an unexpected release of stored energy could cause injury to employees. One-third of all hazardous energy release casualties occur during cleaning and unjamming of equipment (Grund, 1995). Since this activity may not have been foreseen as part of the operation of the machinery, balers may not have guidelines developed to instruct the employee. In these cases freestyle approaches are used. Unexpected energy releases often occur when power is not turned off before servicing a machine, or when power is unexpectedly turned on during the servicing process. OSHA lockout standards require that procedures be developed to place appropriate lockout or tagout devices on energy isolating mechanisms to prevent unexpected energization or unexpected releases of energy. This procedure must be part of a comprehensive energy control program established by the employer.

JamAlert Concept

While great effort has been used to make employers and employees more aware of the dangers that may occur while using a baler, and what precautions they can take during the baling process to prevent injury, additional safety developments can be made. Lockout and tagout procedures reduce the risk of hazardous energy being released, but they can still be easily bypassed, ignored, or forgotten. A control system that automatically detects hazardous operating conditions and responds accordingly is being developed at NIOSH in Morgantown, WV. This system, called JamAlert, detects a jam in a recycling baler by monitoring the strain that the shear bar experiences and the pressure at which the ram operates. If both of these values exceed a limit that is associated with jamming, the power to the baler is eliminated. A trapped key method is used to ensure that the power can not be returned to the machine until the employee is a safe distance away from the operating zone. This allows the jam to be cleared without the threat of an unexpected energy release.

Force Determination Experiment

For the JamAlert system to be capable of detecting a jam, it was necessary to determine the strain that the shear bar experiences during a jam. Finite Element Modeling was used to determine this value by modeling the shear bar and applying a load that simulates the force that jammed material would exert on the shear bar. Since this jamming force is unknown, it was necessary to develop and perform a force determination experiment.

The objective of this experiment was to determine the force exerted on the shear bar by the material as the ram is being operated at the maximum force. This experiment allowed for the comparison of the strain levels for different recyclable materials and different shear bar sharpnesses and their effects on causing the recycling baler to jam.

Apparatus

In order to simulate a jamming situation, a Baldwin testing machine with a load capacity of 200,000 pounds was used to apply a shearing force to a bundle of recyclable material. Attached to the testing machine was a scaled model of the shear bar found in a recycling baler. Force was applied by the testing machine to the shear bar which was lowered onto a bundle of material. This bundle of material was balanced on a block that simulated the ram of the baler. As the shear bar began to compress and cut the material, the bundle of material was free to rotate. The shear bar continued to travel through the material and progressed two inches beyond the end of the ram block. This simulated the action of the ram forcing recyclable material against the shear bar in an actual baler. While the material was being sheared, a load cell with a capacity of 25,000 pounds mounted above the shear bar transmitted a voltage proportional to the force exerted on the shear bar. The signal from the load cell was transmitted to a laptop computer where LabVIEW was used to convert the voltage into force with units of pounds. These readings where then stored sequentially within a spreadsheet. An LVDT was also mounted to the head of the loading machine. This device recorded the distance the shear bar traveled while shearing through the material. This signal was also transmitted to the laptop and LabVIEW was used to convert this signal to distance with units of inches. The distance was recorded simultaneously with the force data in the spreadsheet. Data was recorded through LabVIEW at 100 samples per second. Figure 1 shows the experiment apparatus.

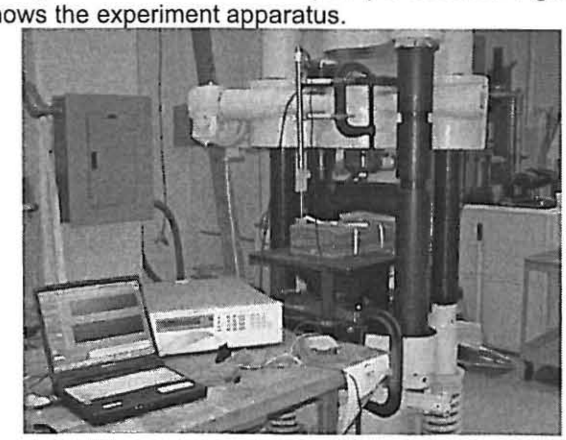

Figure 1: Experiment Setup

Procedure

This experiment was conducted with three different commonly baled materials; cardboard, newspaper, and magazines. Each was bundled into test blocks that were eight inches wide, four inches tall, and sixteen inches long. The material bundle was placed on the block that simulated the ram with the end of the bundle extended past the edge of the block. The shear bar was then lowered right above the top of the bundle. This is where the LVDT output was set at zero. The valve for the testing machine was then opened and the flow control knob was turned 1.5 times. This caused the table of the machine to raise the material into the shear bar at a constant rate of 0.057 inches per second. The material was continuously sheared and compressed until the testing machine shut off at its limit of travel (six inches). This allowed the shear bar to travel through the entire block and go 2 inches past the edge of the ram block. This procedure was repeated four times for each material. The experiment was repeated varying the shear bar sharpness. Each material was tested four times with a sharp shear bar, a shear bar with a 1/64 inch radius on the edge, and a shear bar with a 1/32 inch radius on the edge. Figure 2 shows the experiment after the shear bar traveled four inches through the material.

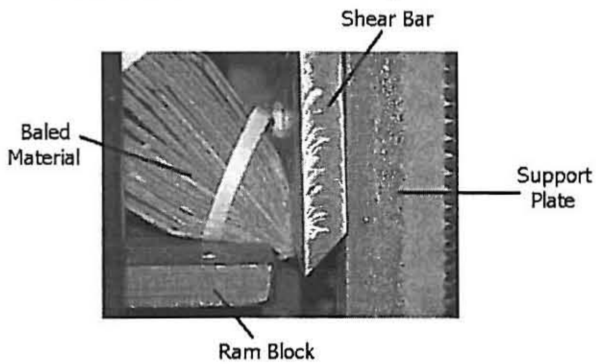

Figure 2: Cardboard Test after Shear Bar Traveled 4 inches

Results

The first group of tests were performed with the sharp shear bar. It was found that the maximum force achieved when testing the cardboard and magazines was approximately 6000 pounds. Newspaper created a larger maximum force which was 8000 pounds. It can be seen that the force increases as the material is initially just compressed. Once the shear bar begins to cut through the material, the force begins to decrease. The force then increases again after the first four inches. This is where the material is compressed in the 0.25 inch gap between the shear bar and the ram. This same trend follows for each of the shear bars. A plot of the data collected for the newspaper tests is shown in Figure 3.

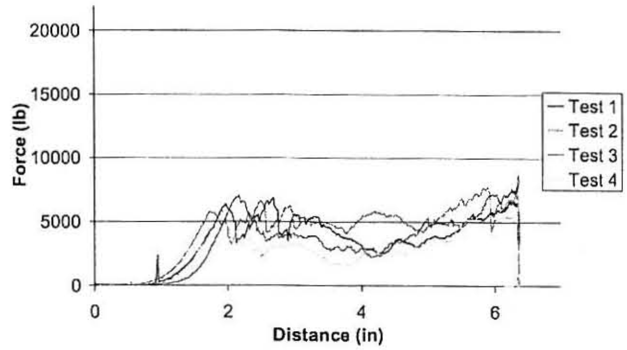

Figure 3: Results for Newspaper using Sharp Shear Bar

The next group of tests was run with a 1/64 inch radius on the edge of the shear bar. With this shear bar, the maximum force found when testing cardboard was about 6000 pounds. For magazines the maximum force increased to 8000 pounds, and for newspapers the maximum force increased to nearly 10,000 pounds. The plotted results are for newspaper with this shear bar shown in Figure 4.

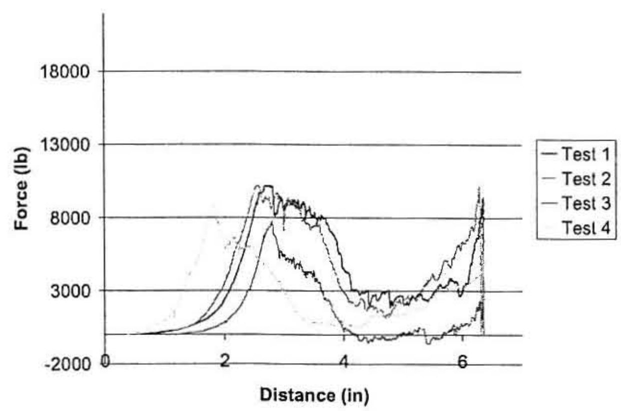

Figure 4: Results for Newspaper using Shear Bar with 1/64" Radius on Edge

The last group of tests was performed with a shear bar that had a 1/32" radius on the edge. For this group of tests, the maximum force found for the cardboard was 10,000 pounds and the maximum force for magazines was 12,500 pounds. The maximum force recorded with newspaper was 20,000 pounds. The forces found with newspaper with this shear bar increased considerably compared to the previous shear bars. The plot of the forces recorded for newspaper is shown in Figure 5.

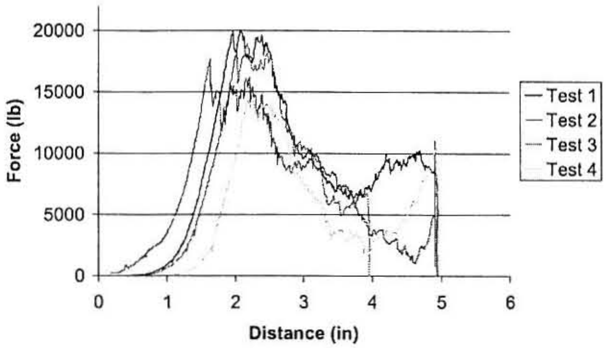

Figure 5: Results for Newspaper using Shear Bar with 1/32" radius on Edge

Since the newspaper test with the shear bar with the 1/32" edge radius provided the most extreme case during testing, the maximum force recorded for newspaper from the third shear bar was used in the finite element model to determine the strain experienced by the shear bar. Through ANSYS the maximum strain was calculated to be 0.028 in/in for an applied force of 20,000 pounds. Graphical representation of the solution is shown in Figure 6. It can be seen that the maximum strain is located on the top of the shear bar directly in the center in front of where the shear bar and block meet.

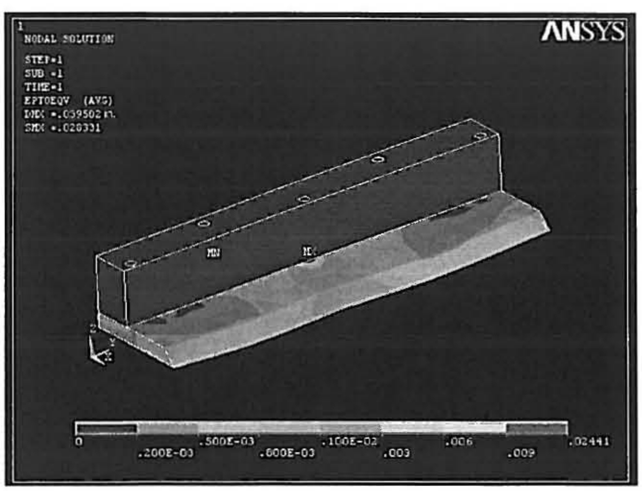

Figure 6: Strain Distribution on Shear Bar

Discussion

The material that is being baled as well as the sharpness of the shear bar both have a significant influence on the maximum force and maximum strain experienced by the shear bar, and factors that contribute to baler jams. From the data collected during the force determination experiment, it can be seen that newspaper required much larger forces than cardboard or magazines. Also as the shear bar became duller the forces it experienced were increased as well.

The strain-induced voltage change that is generated by the strain gage on the shear bar is essential to the success of the JamAlert system. The strain gage currently used is a CEA series strain gage that is made by Vishay Measurement Groups. The 0.5 inch long gage is placed in the middle of the shear bar where the maximum shear was calculated by ANSYS to occur. The model was only solved for the case of material being placed directly in the center to the shear bar. Further testing needs to be completed to realize how the location of the maximum shear would change as the placement of the material changes. The length over which the maximum strain occurs is approximately the same length as the gage. The strain gage is oriented so that it is capable of detecting the strain that is created by the defection of the shear bar. This deflection is caused by the force exerted by the material that is compressed in the 0.25 inch gap between the ram and the bottom of the shear bar. The voltage change generated by the strain gage must be at least 19.5 mV in order to be recognized by the JamAlert system. The equivalent voltage for a strain value of 0.028 using an excitation voltage of 15 V is 21.5 mV which is above the 19.5 mV minimum. This ensures that this maximum strain will be detected for the case of newspaper being baled with the duller shear bar.

The maximum pressure that the ram within the recycling baler could operate was 3000 psi and the diameter of the piston was 3.25 in. From these values it was found that the recycling baler used for this study was capable of exerting 25,000 pounds. It is quite possible for the maximum force of 20,000 pounds to be applied during baling. The baler was never jammed during testing because the pressure gage on the baler was not in operation. Normally the pressure gage would not have allowed the baler to exert such a large force and a jam would have occurred.

Besides using the strain experienced by the shear bar and the ram pressure, another measurement that can be used to predict a jam within a recycling baler is the rate of change of the strain gage voltage. From when the force is initially applied until the maximum force is reached the voltage read by the strain gage continually increases. When this rate of change exceeds a certain value it could be an indicator that a jam is going to occur. For newspaper the voltage rate from the beginning of the test until the maximum voltage was 0.727 mV/s.

When tuning the JamAlert operating system to control a jam-clearing hazard, the material being baled and the sharpness of the blade must be considered. The worst case scenario found during the force determination experiment was newspaper being baled with a shear bar with a 1/32" edge radius. For this situation the JamAlert system would be programmed to recognize a strain of 0.028 as a jam situation. A voltage rate of .727 mV/s or higher could also be considered a possible jam situation. Within this discussion only the most extreme case from baling newspaper was considered. The JamAlert system would need to be tuned differently for other materials or shear bars with a different sharpness since they would produce a different maximum force and thus different strain values for a jam situation.

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