ISSN 1041-9489

SAFETY BRIEF

April 1995 | Volume 11, No. 1

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On the Safety of Stationary Buffing Machines*

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Abstract

When a workpiece locks onto the surface of a cloth buffing wheel, hazards associated with missiles, flailing, and entanglement are introduced which can result in serious injury or death. Classical barrier guards have been proposed which locate rakes or scrapers close to the buffing wheel to dislodge entrapped workpieces. Another approach is to hood the buffing wheel in the same fashion as bench grinders. Here, the restricted geometry between the wheel and the hood entrance is expected to strip off any workpieces entangled in the buffing fibers. A qualitative testing program indicates that the aggressiveness of the ensnarement and the compliant nature of the buffing wheel frustrate these proposed safeguards. New hazards are introduced by the safety devices themselves.

INTRODUCTION

The long term health and safety problems associated with the development of airborne contaminants and the generation of noise have been addressed in the buffing machine literature.[1-6] The literature is silent, however, on the problem of traumatic injuries arising from the use of stationary buffing machines. There is an innocence associated with the buffing machine that probably arises from the fact that one can touch a moving buffing wheel without incident. This benign experience belies the insidious potential of traumatic injuries that can develop because of the interaction of a workpiece with a buffing wheel. Three hazard modes exist: the missile hazard, the flailing hazard, and the entanglement hazard. The missile hazard results from a temporary ensnarement of the workpiece onto the buffing wheel. Here, the workpiece is wrenched from the operator's grip and is rotated with the buffing wheel from which it is subsequently released becoming a high speed missile. The flailing hazard is the same except the workpiece does not separate from the buffing wheel. The high speed and high energy developed in the flailing workpiece can produce serious injury or death to operators standing at their workstations. In contrast, the missile hazard jeopardizes personnel who may be outside the workstation by exposing them to missiles that may travel at over 44.7 m/s (100 mph). Finally, it is possible to en-

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* SERA-Vol. 1, Safety Engineering and Risk Analysis, Editor: F.A. Elia; Book No. H00894 - ASME 1993.

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snare the workpiece in the buffing wheel and simultaneously trap the hand on the workpiece by either snagging or clamping. On multiple horsepower buffing lathes, this results in an entanglement that can easily break the operator's arm and may cause amputation.

Three safety systems have been explored for stationary buffing machines: emergency stop devices, scraping or raking systems, and safety hoods. With respect to hood or barrier guarding, three of the oldest buffing lathe manufacturers have embraced different safety philosophies:

1. "Guards are not recommended when using cloth wheels."
2. "Wheel hoods must be used on lathes when using buffs or polishing wheels."
3. "Buffing wheel guards are accessories."

The lack of consensus is associated with the fact that the intervention systems are type IV devices, i.e., sometimes they improve safety and sometimes they compromise it.[7]

BARRIER GUARDING

The Rake/Scrape Concept

The idea behind the raking or scraping concept is to cause ensnared workpieces to be dislodged from the buffing wheel when they run into a solid scraper or rake located close to the periphery. Scrapers or rakes may be located on the inrunning, outrunning, or rear portions of the buffing wheel. Fig. 1 shows a typical buffing lathe equipped with a hood that contains an adjustable scraper at the top portion of the guard, an adjustable scraper at the bottom portion of the guard, adjustable side scrapers at the front of the guard, and an adjustable rake which is horizontally disposed at the rear of the guard. This guarding concept would be simplicity itself if the buffing wheel, rake/scraper, and workpiece were rigid since the problem reduces to one of geometry. Under these circumstances, the rake would be adjusted such that its clearance with the wheel would preclude passage of a workpiece. Unfortunately, buffing wheels are compliant and even a zero clearance will allow a workpiece to bypass the scraper when sufficient wedging action is developed to deflect the buffing wheel and allow an escape geometry as depicted in Fig. 2A. Three other failure modes of the raking/scraping system are shown in Figs. 2B, 2C, and 2D which illustrate bypass geometries created by bending or breaking of the scraper structure, a workpiece that slips through the tangs, and a workpiece that passes through the clearance between the rake and the buffing wheel. It should be noted that the clearance in Fig. 2D is constantly growing as the buffing wheel wears down.

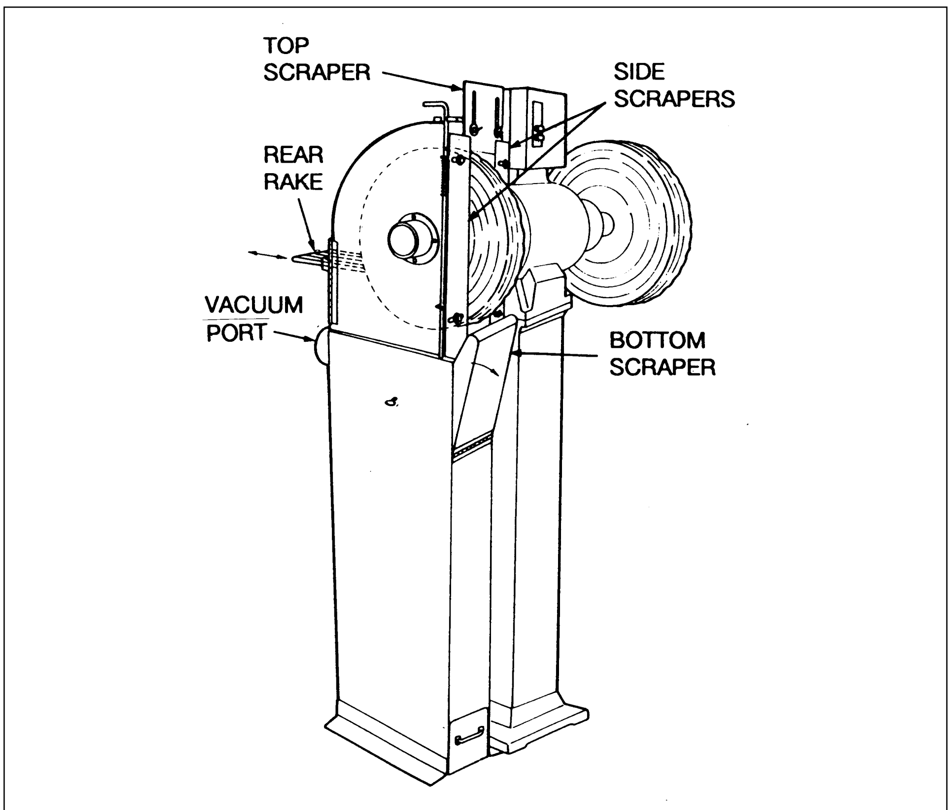

Figure 1. L'Hommedieu Hood System

Hood Guarding

The rigid hood presents a fixed or adjustable ingress geometry that may be used to restrict the passage of a workpiece. This simple interference concept is independent of the compliant nature of the wheel. Several elementary observations are worth noting:

1. Small workpieces may pass through the hood without interference.
2. Small workpieces may impact the edges of the inrunning hood members and become dislodged from friction or ensnarement wheel contact.
3. Large workpieces will not enter the hood.
4. The ingress portion of the hood will usually be large enough to allow the passage of an operator's hand.
5. Workpieces of any size may impact against the ingress portions of the hood when they are locked onto the wheel, buried between buffing plies, or held against the buffing wheel. These impacts may result in ricochet.
6. The operator's hand may be thrown against the hood structure at the inrunning side of the buffing wheel.
7. The operator's hand may be drawn or forced into the hood and entrapped between the buffing wheel and the hood elements.
8. The hood may not expose enough of the buffing wheel to allow certain parts to be buffed. For example, internal buffing of a closed frame may be impossible.

THE TESTING PROGRAM

Gold Tech Scraper System

The escape geometries associated with the compliant behavior of the buffing wheel and the structural integrity of the scraper system depend on the development of impact forces of sufficient magnitude to modify the initial geometry of the system. One visualizes that asperities on the workpiece snag the fibers of the buffing wheel causing kinetic energy to be transferred into the workpiece. Testing was performed to find out if the developed energy is sufficient to bypass the Gold Tech heavy duty scraper system shown in Fig. 3 where the rear scraper bar is a 3.18 cm (1.25 in.) steel square tube.

Test Setup. A 40.6 cm (16 in.) diameter and 6.35 cm (2.5 in.) wide #3 muslin cloth wheel was mounted onto a stationary buffing lathe possessing an operating speed of 1800

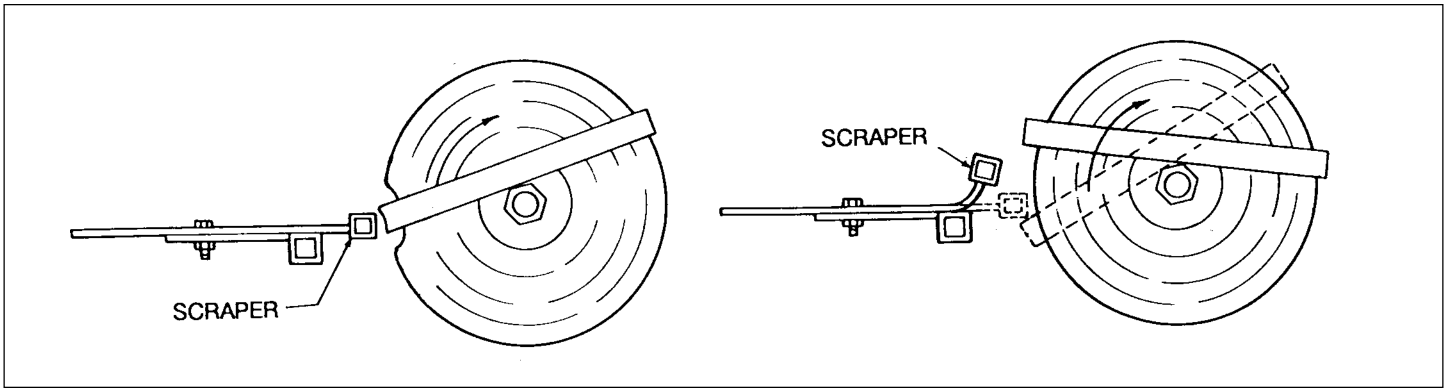

Figure 2A. Compliant wheel allows workpiece to bypass scraper.

Figure 2B. Workpiece bends or breaks scraper.

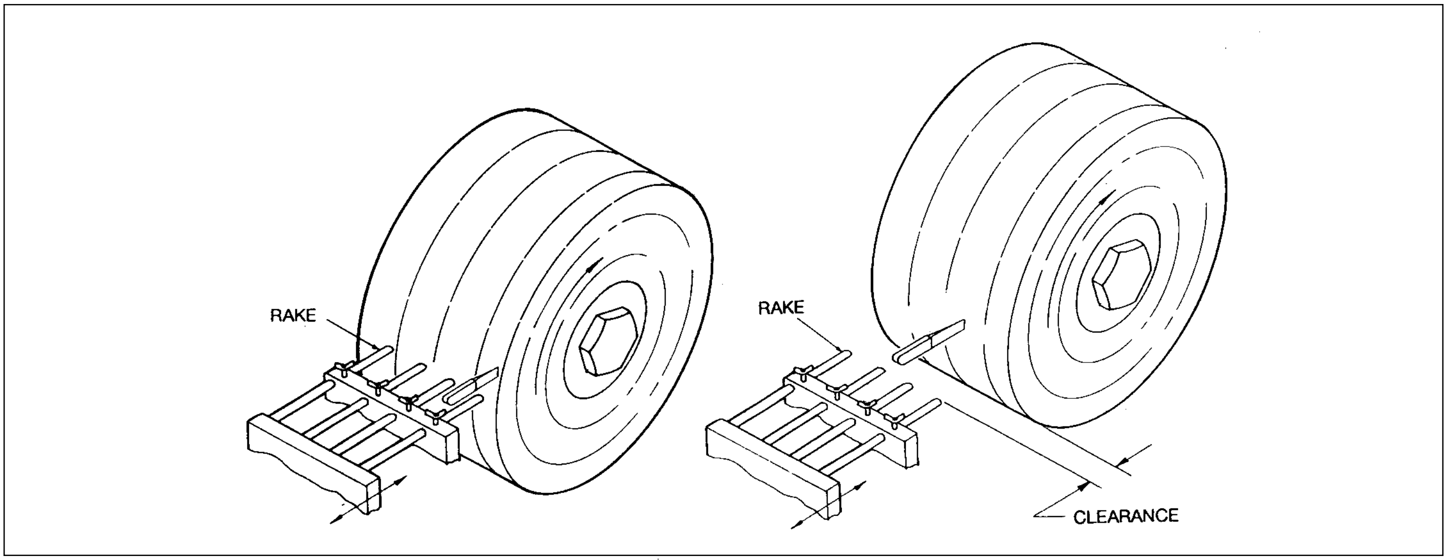

Figure 2C. Workpiece slips through tangs.

Figure 2D. Workpiece passes through clearance.

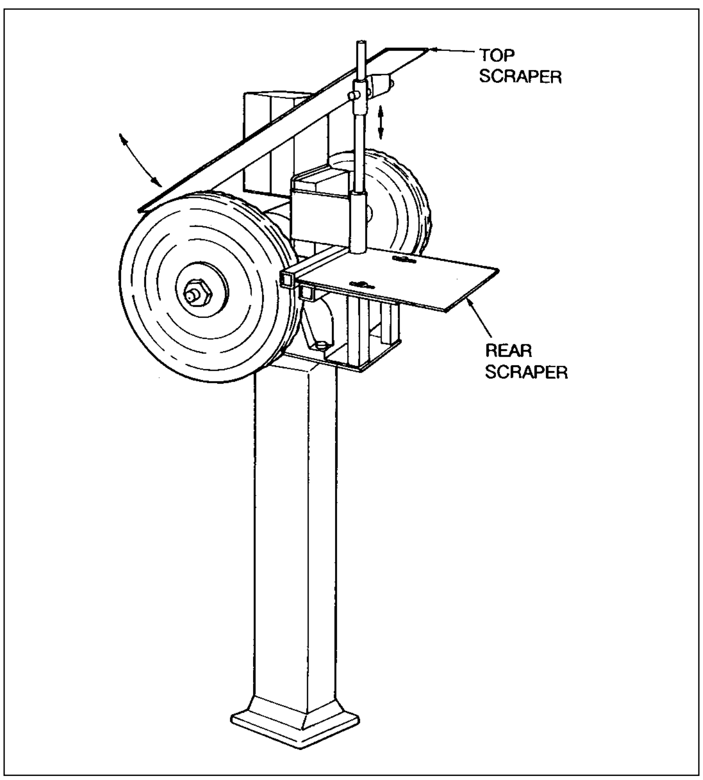

Figure 3. Gold Tech Scraper System

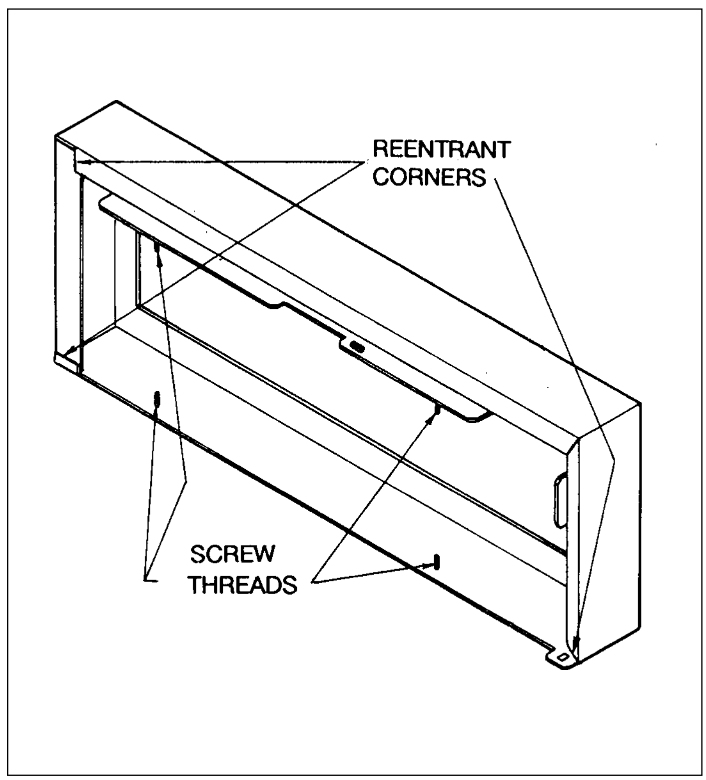

Figure 4. Test frame

rpm. Clearance between the Gold Tech rear scraper and the buffing wheel was set once at 3.18 cm (1.25 in.), 2.54 cm (1 in.), and 1.27 cm (0.5 in.) and twice at zero; clearance between the Gold Tech top scraper and the buffing wheel was set at 2.54 cm (1 in.) in all five tests. The test specimen adopted was an exemplar of a slot machine cover associated with an industrial accident as illustrated in Fig. 4. The test procedure involved introducing the workpiece into the full speed buffing wheel automatically utilizing a string trigger device.

Test Results.

Observation 1: The projections and reentrant corners on the test specimen caused the buffing wheel to ensnare the workpiece almost instantly in every trial. Microscopy of the accident cover revealed buffing wheel fibers trapped at each of the points indicated in Fig. 4.

Observation 2: All five tests led to bypassing of both the rear scraper system using clearances of zero to 3.18 cm (1.25 in.) and the top scraper using a clearance of 2.54 cm (1 in.).

Observation 3: Missiles were produced in all five trials; one had a range of approximately 4.65 m (50 ft) and one achieved an altitude of 1.86 m (20 ft) as displayed in Fig. 5. In the associated industrial accident, a wooden 2 x 12 was used in place of the 3.18 cm (1.25 in.) square steel tube. The workpiece chopped an 8.89 cm (3.5 in.) x 1.91 cm (0.75 in.) fragment out of the 2 x 12 and allowed the workpiece to become an accident-causing projectile.

Observation 4: In one trial using a 1.27 cm (0.5 in.) clearance, bypassing was achieved by displacing the rear steel tubing scraper as shown in Fig. 6. With improved structural integrity, the workpiece may have been stripped from the buffing wheel.

Observation 5: In two trials using zero clearance, bypass was accomplished without displacing the rear steel tubing scraper. The workpiece simply displaced the buffing wheel as captured in Fig. 7. Clearly, this behavior is independent of the structural integrity of the scraping system.

Observation 6: In two trials, the workpiece bypassed the rear and top scraping systems multiple times before becoming airborne; one flailed three times and the other four times.

Observation 7: The top scraper system was deflected from the trajectory of the workpiece in each of the five tests as shown in Fig. 8.

L'Hommedieu Hood System

It is possible to fashion a guarding system with zero clearance side and bottom scrapers on the inrunning portion of the hood. In addition, a heavy duty rake with zero clearance can be located horizontally at the rear of the buffing wheel. Finally, the hood guard system can introduce zero clearance side and top scrapers at the outrunning portion of the hood. Sufficiently small workpieces located within the width of the wheel will bypass any side scrapers. Furthermore, small workpieces may pass through the tangs of the rear rake without interference. The front scrapers on the top and bottom of the hood may be bypassed by workpieces which become buried between the plies of the buffing wheel. In addition, we have previously shown that workpieces may bypass rigid rakes and scrapers by deforming the buffing wheel.

Workpieces may follow the periphery of the buffing wheel when they become ensnared or when the friction force is high enough to overcome the resistance furnished by the operator. If the operator is unable to release the workpiece because his hand is trapped onto the workpiece or because his reaction time does not permit a timely release, his hand will initially be drawn downward. The hand may also follow the surface of the buffing wheel. The use of hoods introduces a tunnel into which an operator's hand may be drawn. Entrapment is a natural consequence and involves wedging of the hand between the sides or bottom of the hood and the buffing wheel at the inrunning side. The operator's hand is exposed to the abrasive action of the buffer and any crushing that arises from the inrunning nip.

Test Setup. A floor-mounted heavy duty guarding hood manufactured by L'Hommedieu, as illustrated in Fig. 1, was tested using a stationary buffing lathe with an operating speed of 1800 rpm. Tests were conducted using a 40.6 cm (16 in.) diameter and 6.35 cm (2.5 in.) wide #3 muslin cloth wheel and a 20.3 cm (8 in.) diameter and 6.35 cm (2.5 in.) wide-sewed piece buffing wheel. The top, bottom, and side scrapers and the rear rake were adjusted so that they barely touched the 40.6 cm (16 in.) diameter wheel; only the rear rake and side scrapers contacted the 20.3 cm (8 in.) diameter wheel while the top and bottom scrapers were set to minimize clearances. The exemplar frame shown in Fig. 4, a handle, fork, knife, and hatchet, were introduced into the 40.6 cm (16 in.) diameter wheel during 22 trials; six tests were conducted on the 20.3 cm (8 in.) diameter wheel using the exemplar frame, knife, and handle. Anthropometric arms were attached to the workpieces using tape in seven of the 40.6 cm (16 in.) diameter wheel tests and three of the 20.3 cm (8 in.) diameter wheel tests. The test procedure involved introducing the workpiece into the full speed buffing wheel automatically utilizing a forklift and tape.

Test Results.

1. *Ricochet Hazard with Bottom Scraper:* Using the 40.6 cm (16 in.) diameter buffing wheel, a violent ricochet was created by both a frame and a hatchet which impacted the horizontal edge of the bottom scraper. The resulting missiles invaded the operator's workstation in both cases. A typical frame ricochet is shown in Fig. 9.

2. *Impact Hazard with Bottom and Side Scrapers:* Using the 40.6 cm (16 in.) diameter cloth buffing wheel, violent impacts against the bottom and side scrapers were obtained in seven frame tests and one hatchet test. A typical frame impact with the side scraper is depicted in Fig. 10. Similar results were obtained with the 20.3 cm (8 in.) diameter cloth buffing wheel in one frame test and one knife test. It should be noted that these impacts may occur at the tangential velocity of the buffing wheel which was 38.4 m/s (86 mph) for the 40.6 cm (16 in.) diameter buffing wheel operating at 1800 rpm.

3. *Entrapment Hazards between Hood and Buffing Wheel:* Using the 40.6 cm (16 in.) diameter buffing wheel, entrapment was realized in two cases using the handle and in one case using the fork. A typical entrapment scenario is displayed in Fig. 11 for the handle. Tests involving the 20.3 cm (8 in.) diameter cloth buffing wheel entrapped a knife between the left side shield and the wheel and a handle between the bottom scraper and the face of the buffer. It should be noted that an emergency stop device may mitigate additional injuries from the guard after entrapment occurs.

4. *Entrapment between Workpiece and Hood:* Testing with the frame led to a scenario where the workpiece wedged

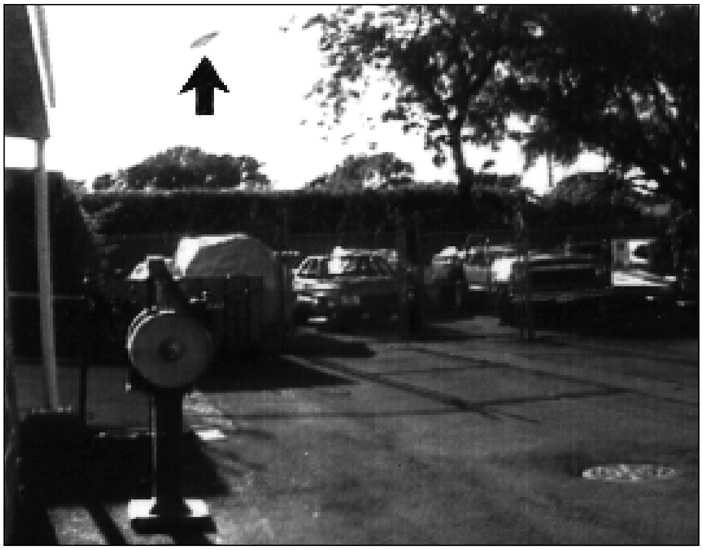

Figure 5. Missile achieves altitude of 1.86 m (20 ft).

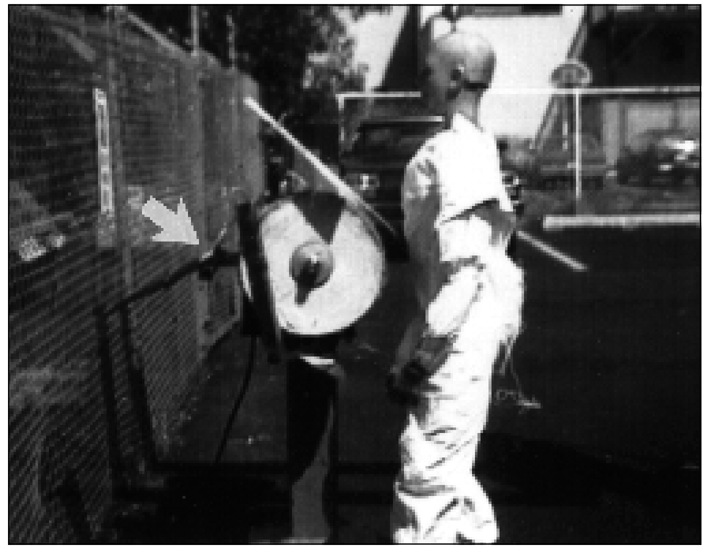

Figure 6. Workpiece displaces rear scraper.

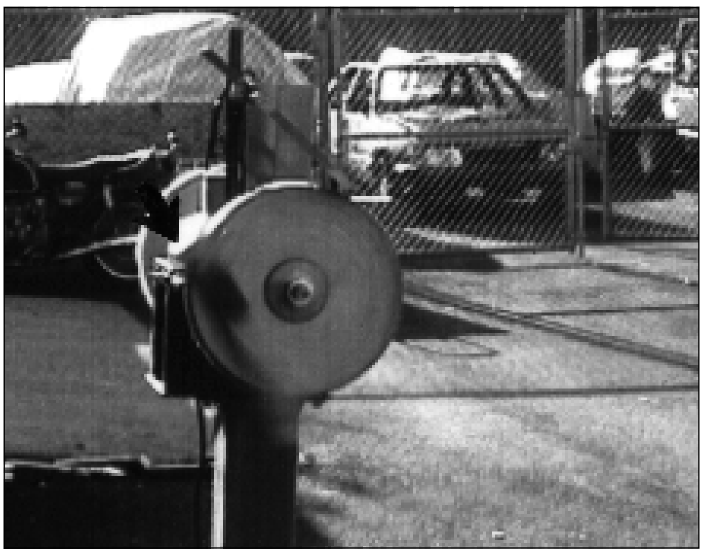

Figure 7. Workpiece bypasses rear scraper.

Figure 8. Workpiece deflects top scraper.

Figure 9. Frame ricochet.

Figure 10. Frame impact with side scraper.

Figure 11. Entrapment between hood and buffing wheel.

Figure 12. Entrapment between workpiece and hood.

itself between the buffing wheel and the bottom edge of the hood. This action caused the workpiece to clamp itself to the hood as shown in Fig. 12 where an operator's hands are entrapped in the resulting pinch point. Four frame tests with the 40.6 cm (16 in.) diameter buffing wheel gave rise to this type of entrapment.

5. *Missile Hazards:* In four of the tests which involved inserting a knife between the plies of a buffing wheel, missiles were produced. Two tests used the 20.3 cm (8 in.) diameter buffing wheel and two tests used the 40.6 cm (16 in.) diameter buffing wheel. Fig. 13 shows a knife missile being thrown from the egress portion of the hood using a 40.6 cm (16 in.) diameter buffing wheel. It is implicit in this observation that the workpiece bypassed all of the interference devices.

Delta Wheel Guard

For smaller buffing wheels (20.3 cm diameter), Delta manufactures the wheel guard shown in Fig. 14. An adjustable top scraper is located at the outrunning portion of the hood; a fixed tray is located at the bottom which will capture particulates thrown from the wheel. The Delta hood and the L'Hommedieu hood contain vacuum ports at the rear for environmental control.

Test Setup. The Delta wheel guard shown in Fig. 14 was tested using a stationary buffing lathe with an operating speed of 1800 rpm. Thirteen tests were conducted using a 20.3 cm (8 in.) diameter and 6.35 cm (2.5 in.) wide sewed piece buffing wheel. The top scraper was adjusted so it had zero clearance with the buffing wheel. Using the exemplar frame shown in Fig. 4, a knife, and a handle were introduced into the 20.3 cm (8 in.) diameter buffing wheel running at 1800 rpm. Anthropometric hands were attached to the workpieces in seven of the tests. The test procedure involved automatically introducing the frame and handle into the full speed buffing wheel utilizing a forklift and tape. During the knife tests, the knife was buried in between the plies of a stationary buffing wheel and then the buffing lathe was energized.

Test Results.

1. *Missile Hazard:* In five tests where the knife was inserted between the plies of the buffing wheel, the knife bypassed the zero clearance top scraper and became a missile.

2. *Impact Hazard with Bottom Tray:* In one test using a handle and in three tests using the frame, the hand was impacted against the bottom of the tray. Fig. 15 shows the accident geometry when the hand is gripping a handle.

3. *Entrapment Hazard between Hood and Buffing Wheel:* In four cases, the hand was entrapped between the vertical portions of the hood and the side of the buffing wheel. In two cases, the anthropometric hand grasped a handle and in two cases a knife.

TEST SUMMARY

The unguarded buffing wheel gives rise to entanglement, flailing, and primary missile hazards where primary refers to a missile thrown directly from the buffing wheel. Barrier guards introduce three additional hazards: impact, entrapment, and secondary missiles which are either generated by the impact of a workpiece with the egress scraper or by ricochet of the workpiece with the ingress hardware of a hood. The following summary of our qualitative testing program organized by hazard categories shows the relationship among large and small workpieces, rakes, scrapers, and hoods. It should be noted that the program only deals with hazards and not their associated frequencies. The intervention devices in the summary that appear with the phrase "not eliminated" may reduce the frequencies even if they do not eliminate the hazards. In our test program, all forty-six tests resulted in the introduction of at least one hazard.

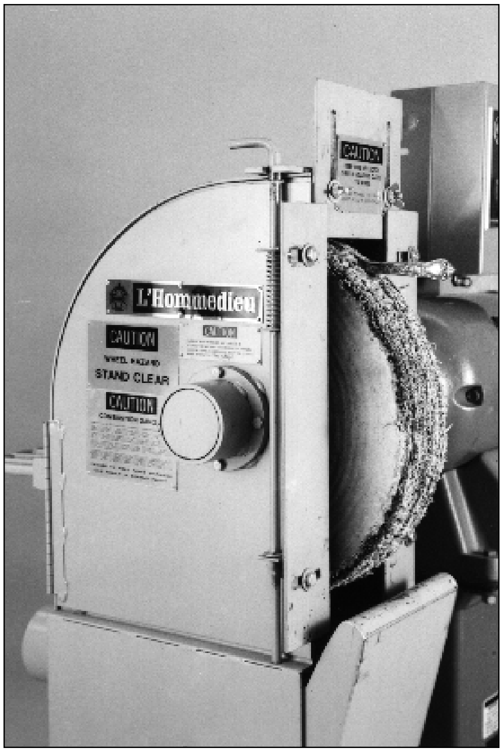

Figure 13. Knife missile.

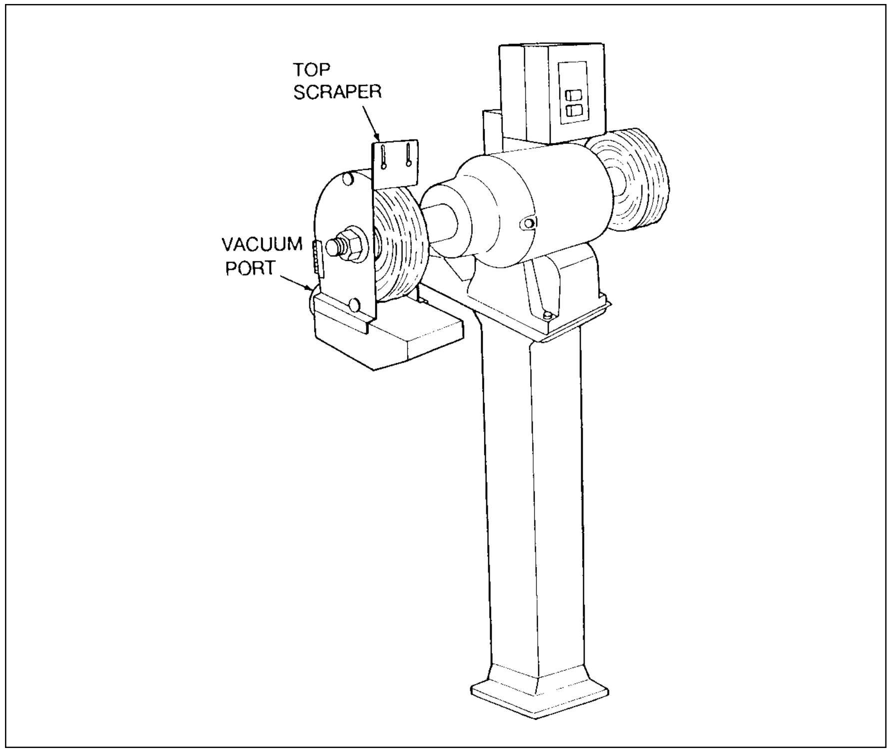

Figure 14. Delta wheel guard

Primary Missile Hazard

1. Eliminated by the hood for large workpieces.
2. Not eliminated by the hood for small workpieces.
3. Not eliminated by the rake.
4. Not eliminated by the scraper.

Flailing Hazard

1. Eliminated by the hood for large workpieces.
2. Not eliminated by the hood for small workpieces.
3. Not eliminated by the rake.
4. Not eliminated by the scraper.

Entanglement Hazard

1. Eliminated by the hood for large workpieces.
2. Not eliminated by the hood for small workpieces.

Secondary Missile Hazards

1. Introduced ricochet hazard at the ingress of the hood.
2. Introduced missile hazard caused by fracture of the egress scraper by workpiece. May be eliminated by increasing the structural integrity of the egress scraper system.

Entrapment Hazard

1. Introduced by the hood externally for large workpieces.
2. Introduced by the hood internally for small workpieces.

Impact Hazard

1. Always introduced by the hood for large workpieces.
2. Sometimes introduced by the hood for small workpieces.

OBSERVATIONS AND RECOMMENDATIONS

1. The screw projections and reentrant corners in the frame used throughout the testing program were so aggressive that seizure with the cloth buffing wheel resulted in every trial. Snagging occurred instantaneously in each contact of the frame with the wheel.
2. The fibers in the cloth buffing wheel were so strong and so numerous in their attachment to the frame that the resulting ensnarement usually survived multiple impacts with “zero clearance” rakes and scrapers. Even contact with a stationary wheel gave rise to a joint that would overcome human strength.
3. When a workpiece attaches itself to the buffing wheel, the hinged joint creates a dynamic system whose first order modelling is a double pendulum. This gives rise to particle speeds at the free end of the workpiece that exceed the tangential speed of the buffing wheel. The multiplier could well be an order of magnitude.
4. Flailing or the production of primary missiles was achieved in every test involving rakes, scrapers or combinations of these devices.
5. Only for large workpieces will the hood completely eliminate flailing, primary missile, and entanglement hazards.
6. The hood introduces three additional hazards to buffing technology: entrapment, secondary missiles, and impact.

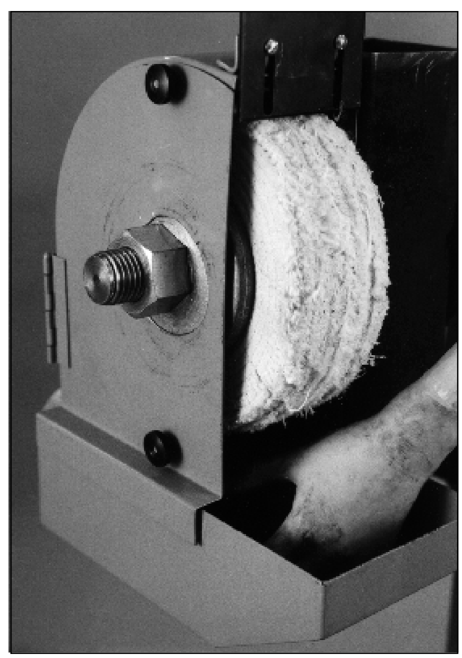

Figure 15. Impact hazard with bottom tray.

This violates the universal safety philosophy that a safety device should not create new hazards.[7]

7. Until better intervention devices become available, workpieces must not be allowed to snag the buffing wheel. Only smooth surfaces should be buffed; workpieces with reentrant corners and aggressive asperities must be avoided.

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SAFETY BRIEF

April 1995 – Volume 11, No. 1

Editor: Paula L. Barnett

Illustrated and Produced by Triodyne Graphic Communications Group