ISSN 1041-9489

SAFETY BRIEF

August, 2001 Volume 19, No. 2

Triodyne Inc.

Consulting Engineers & Scientists – Safety Philosophy & Technology

5950 West Touhy Avenue Niles, IL 60714-4610 (847) 677-4730

FAX: (847) 647-2047

e-mail: infoserv@triodyne.com

www.triodyne.com

MECHANICAL ENGINEERING:
Triodyne Inc.
(Est. 1969)
Officers
Ralph L. Barnett
Dolores Gildin
S. Carl Uzgiris, Ph.D.

Mechanical Engineering
Ralph L. Barnett
Dennis B. Brickman
Michael A. Dilich
Christopher W. Ferrone
Suzanne A. Glowiak
John M. Goebelbecker
Crispin Hales, Ph.D.
Dror Kopernik
Woodrow Nelson
Cheryl A. Pattin, Ph.D.
Peter J. Poczynok
Audrone M. Stake, Ph.D.
William G. Switalski
George J. Trezek, Ph.D.
S. Carl Uzgiris, Ph.D.
Raymond B. Wambaja
James R. Wingfield, Ph.D.

Library Services
Marna S. Sanders
Betty Bellows
Donna Klick
John Kristelli
Florence Lasky
Katherine Moyer
Jackie Schwartz
Joyce Styler

Information Products
Expert Transcript Center (ETC)
Marna S. Sanders

Graphic Communications
Robert Koutny
Charles D'Eccliss

Training and Editorial Services
Paula L. Barnett

Vehicle Laboratory
Charles Sinkovits
Matthew J. Ulmenstine

Model Laboratory
2721 Alison Lane
Wilmette, IL 60091-2101
Bill Brown

Photographic Laboratory
7903 Beckwith Road
Morton Grove, IL 60053
Larry Good

Business Systems
Chris Ann Gonatas
Cheryl Black
Sandie Christiansen
Rita Curtis
Sandra Prieto

Facilities Management
Peter Warner

SAFETY RESEARCH:
Institute for Advanced Safety Studies
(Est. 1984)
5950 West Touhy Avenue
Niles, IL 60714-4610
(847) 647-1101

Chairman
Ralph L. Barnett
Director of Operations
Paula L. Barnett
Information Services
Marna S. Sanders
Senior Science Advisor
Theodore Liber, Ph.D.

SAFETY PRODUCTS:
Triodyne Safety Systems, L.L.C.
(Est. 1998)
5950 West Touhy Avenue
Niles, IL 60714-4610
(847) 677-4730
FAX: (847) 647-2047

Officers/Directors
Ralph L. Barnet
Paula L. Barnett
Joel I. Barnett
President
Peter J. Poczynok
Vice President of Operations
Peter W. Warner
Senior Science Advisor
Theodore Liber, Ph.D.
Mechanical Engineering
Ralph L. Barnett
Peter J. Poczynok
Aquatics Safety Consultant
Ronald M. Schroader

On the Safety of Infeeding Vertical Garden Shredders

By Dennis B. Brickman* and Ralph L. Barnett**

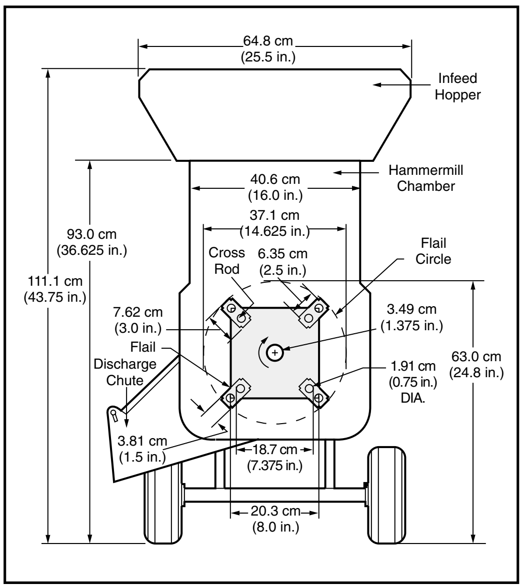


Figure 1 - Chipper/Shredder Geometry

ABSTRACT

This paper addresses consumer garden shredders of the hammermill type with vertical hoppers that are manually fed. The purpose of this paper is to show that garden materials presented to a vertical garden shredder through the inlet hopper will not pull an erectly standing operator's hand into the flails. In order for an erectly standing operator to contact the flails, it is necessary for the shoulder to move downward. Experiments demonstrate that the operator's shoulder moves insignificantly downward during pull-in excursions using various garden materials that are attached to the operator's hand through snagging mechanisms, hand friction, and entanglement.

INTRODUCTION

The principle hypothesis of this paper is that an erectly standing operator's shoulder and torso will not move downward during a pull-in excursion of garden materials into the shredder hopper. An operator's arm is not long enough to touch the flails while maintaining an erect standing position. Dealing first with this aspect of the problem, Fig. 1 defines the geometry of a consumer hammermill chipper/shredder. The cutaway indicates the flails reach their apex at a distance of 63.0 cm (24.8 in.) from the ground. Adults in an erect standing position with dangling arms exhibit a knuckle clearance with respect to the

ENVIRONMENTAL:
Triodyne Environmental Engineering, Inc.
(Est. 1989)
5950 West Touhy Avenue
Niles, IL 60714-4610
(847) 677-4730
FAX: (847) 647-2047

Officers
Ralph L. Barnett
S. Carl Uzgiris, Ph.D.

MANUFACTURING:
Alliance Tool & Manufacturing Inc.
(Est. 1945)
91 East Wilcox Street
Maywood, IL 60153-2397
(773) 261-1712
(708) 345-5444
FAX: (708) 345-4004

Officers
S. Carl Uzgiris, Ph.D.
Ralph L. Barnett

General Manager
Ramesh Gandhi

Plant Manager
Bruno Stachon

Founders/Consultants
Joseph Gansacz
Albert Kanikula

CONSTRUCTION:
Triodyne-Wangler Construction Company Inc.
(Est. 1993)
5950 West Touhy Avenue
Niles, IL 60714-4610
(847) 647-8866
FAX: (847) 647-0785

Officers/Directors/Managers
Joel I. Barnett
William A. Wangler
Joseph Wangler
Ralph L. Barnett

CONSTRUCTION PRODUCTS:
Triodyne-Wangler Construction Specialties, L.L.C.
(Est. 1999)
5950 West Touhy Avenue
Niles, IL 60714-4610
(847) 647-8866
FAX: (847) 647-0785

Officers
Joel I. Barnett
William A. Wangler
Joseph Wangler
Ralph L. Barnett

BUILDING MAINTENANCE:
Alliance Building Maintenance Corporation
(Est. 1999)
5950 West Touhy Avenue
Niles, IL 60714-4610
(847) 647-1379
FAX: (847) 647-0785

Officers
William A. Wangler
Joseph Wangler
David J. Smith
Joel I. Barnett
Ralph L. Barnett

CONSULTANTS:
Richard M. Bilof, Ph.D.
Electromagnetic Compatability
Richard Gullickson
Industrial Hygiene/Safety/Chemistry
Beth A. Hamilton
Information Science
David W. Levinson, Ph.D.
Senior Metallurgical Advisor
Steven R. Schmid, Ph.D.
Food Processing Equipment
Diane Moshman
Chemical/Environmental Engineering
Harry Smith
Electrical Engineering
Kim M. Mniszewski
Fire and Explosion

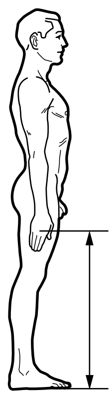
* Senior Mechanical Engineer, Triodyne Inc., Niles, IL

* Professor, Mechanical and Aerospace Engineering, Illinois Institute of Technology, Chicago and Chairman, Triodyne Inc., Niles, IL

No Charge

ground. For males and females in the 1, 50, and 99 percentile classes, the ground clearance is shown in Table 1 [1 - 3]. In each case, hand-flail contact will not occur because the clearance is greater than 63.0 cm (24.8 in.), the top of the flails. This clearance is conservative because the serpentine route through the hopper to the flails lengthens the path.

Table 1 - Adult Knuckle Height (1in. added for shoes)



Knuckle Height (in.)

1	Percentile - Male	------ 27.7
50	Percentile - Male	------ 31.0
99	Percentile - Male	------ 34.5
1	Percentile - Female	--- 25.9
50	Percentile - Female	--- 27.9
99	Percentile - Female	--- 32.5

The safety from this geometry will be maintained throughout a pull-in scenario if it can be shown that the shoulder remains stationary or moves upward. Shoulder immobility was in fact demonstrated in seventeen test configurations which varied the initial position of the hand relative to the top of the hopper. Furthermore, various snagging profiles were studied that involved nailing tree branches to leather gloves and enveloping the wrist of an anthropomorphic dummy with garden jute twine. In every case, the downward shoulder movement was insignificant. This result was also established analytically in reference 4 by modeling the arm as a ballistic pendulum under an impulse loading caused by pulling garden materials through an operator's grip at high speeds [4]. Material is snatched from an operator's hand at the peripheral speed of the hammermill flails, 252.7 km/h (157 mph). When material trails the leading edge of the fist by 30.5 cm (1 ft), the impulse time is approximately 0.00436 sec. When this time is compared to the arm's natural period of vibration, 1.13 sec., the impulse time is approximately 0.386% of the period. Under these circumstances, there is no hand movement until after the vegetation has emerged from the grip. Snagging scenarios provide even smaller impulse times than the friction grip. The impulse analysis indicates that the shoulder actually moves upward during the impulse phase as shown in the appendix of reference 4.

TESTING PROTOCOL

Figure 2 shows the dynamic test setup that was used to study the pull-in phenomenon in a consumer rotating hammermill chipper/shredder. The particular chipper/shredder studied operated at 3600 rpm, weighed 100.7 kg (222 lb), and had its flails removed to preclude premature cutting of the fibers. A 175.3 cm (69 in.) tall anthropomorphic dummy weighing 77.6 kg (171 lb) is posed next to the infeed hopper with its right hand positioned in the central hopper region. The dummy has its feet resting on the ground and its waist supported by an overhead strap which allows the torso to rotate forward if a downward tension is applied to the arm. The support system offers no restoring resistance. Further, in some cases, the pull-in scenario begins with an arm that is bent at the elbow. Others begin with a fully extended arm facing in a downward direction.

Figure 2 - Dynamic Test Setup

In the snagging and hand friction tests, the pull through force was transmitted through a clothesline which was threaded through the infeed hopper, hammermill chamber, and discharge chute of the test chipper/shredder. The tensile strength of the clothesline was 754 pounds and various appliances were tied to its upper end during the tests. In the entanglement tests, garden jute twine was tied around the anthropomorphic dummy's wrist and then threaded through the chipper/shredder. Typically, the chipper/shredder was started in its unclutched state and its engine was brought to full speed; the clutch was then engaged and the hammermill was allowed to reach its full 3600 rpm. The pull-in force was initiated by pulling on the trailing edge of the clothesline or garden jute twine which emerged from the discharge chute. This caused the clothesline to wrap around the crossbars of the hammermill to achieve a pull-in speed of 161.9 km/h (100.6 mph); this speed is 64% of the peripheral speed of the flails. Still photography and videotaping captured the test trials.

TESTING - HAND GRIP

Test Setup

When vegetation is grasped by a hand, there is a trailing length behind the leading or downward edge of the hand. As the trailing length is pulled through the hand, the resisting friction force causes an impulse to be delivered to the hand. This impulse is equal to the friction force times the pull through time; here, the friction force is equal to two times the coefficient of friction between the vegetation and the gloved or bare hand. A constant force grip of 45 pounds was simulated by using a 45 pound constant force spring (Fig. 3) with a length of 30.5 cm (1 ft) to represent a vegetation trailing length of 30.5 cm (1 ft). It should be noted that a grip of 45 pounds is much greater than the force required to feed materials into the infeed hopper.

Testing

Four tests were conducted with an erectly standing anthropomorphic dummy using a bent elbow which positioned the hand over the center of the infeed hopper. In each case, the capacity of a constant force spring was verified within very close tolerances to be 45 pounds before attaching it to the dummy's hand. The pull force was initiated and the response of the dummy was recorded. Fig. 4 is a typical critical sequence for one of the tests which shows the unloaded arm in frame 4A, a following frame 4B, where the constant force spring has been pulled through, and frame 4C, which illustrates the final position of the hand, arm, and shoulder after all motion stopped. Figure 5 is a photograph of the final hand position. It can be observed in this sequence that the downward vertical motion of the shoulder is imperceptible. In addition, Fig. 5 indicates that in the final position the hand has not entered the hammermill chamber. The results did not vary in a significant way among the four tests. In all cases, the pull through phenomenon is so fast that the 30.5 cm (1 ft) trailing length of the constant force spring completely passes through the hand in one video frame (1/30 of a second).

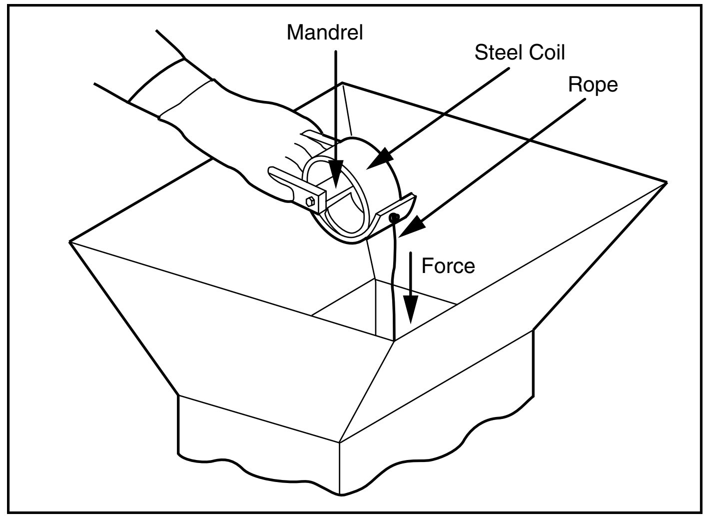
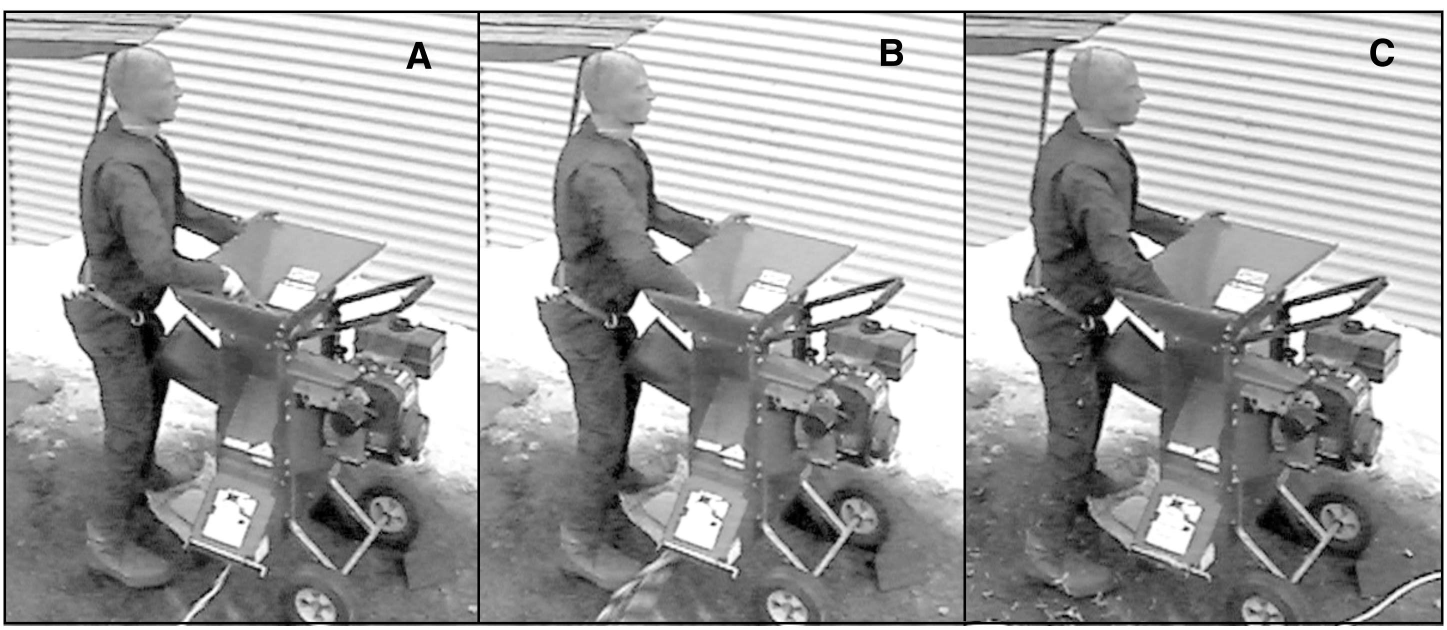


Figure 3 - Constant Force Spring



A) Unloaded Arm *B) Constant Force Spring Pulled Through Hand* *C) Final Arm Position*

Figure 4 - Video Sequence - Constant Force Spring

Fig. 5 - Final Hand Position - Constant Force Spring

TESTING - SNAGGED GLOVE

Test Setup

To study the effect of snagging during a feeding scenario, a high strength connection was constructed by nailing a leather palmed glove to a branch with a single or double nail. The branch in turn was fastened to a clothesline which was threaded through the chipper/shredder. Four different species of branches were used . Each test branch was nominally 1.27 cm (0.5 in.) in diameter.

Static Connection Tests

Single or double nailed joints were created by nailing the palm of a new leather glove to branches of four species. Static tests were conducted to determine the tenacity of the connection. In a typical static test, the gloved hand was held in a vise and the nailed branch was pulled horizontally by a rope attached to a winch. Inserted in this pulling line was a load cell connected to a Chatillon gauge which recorded the maximum pull force. Table 2 tabulates the static test results where the failure modes are indicated. The failure modes involved the nails pulling out of the palm of the leather glove or the branches pulling out of the nails; no nail failures were observed. The highest connection resistance was recorded at 122 pounds.

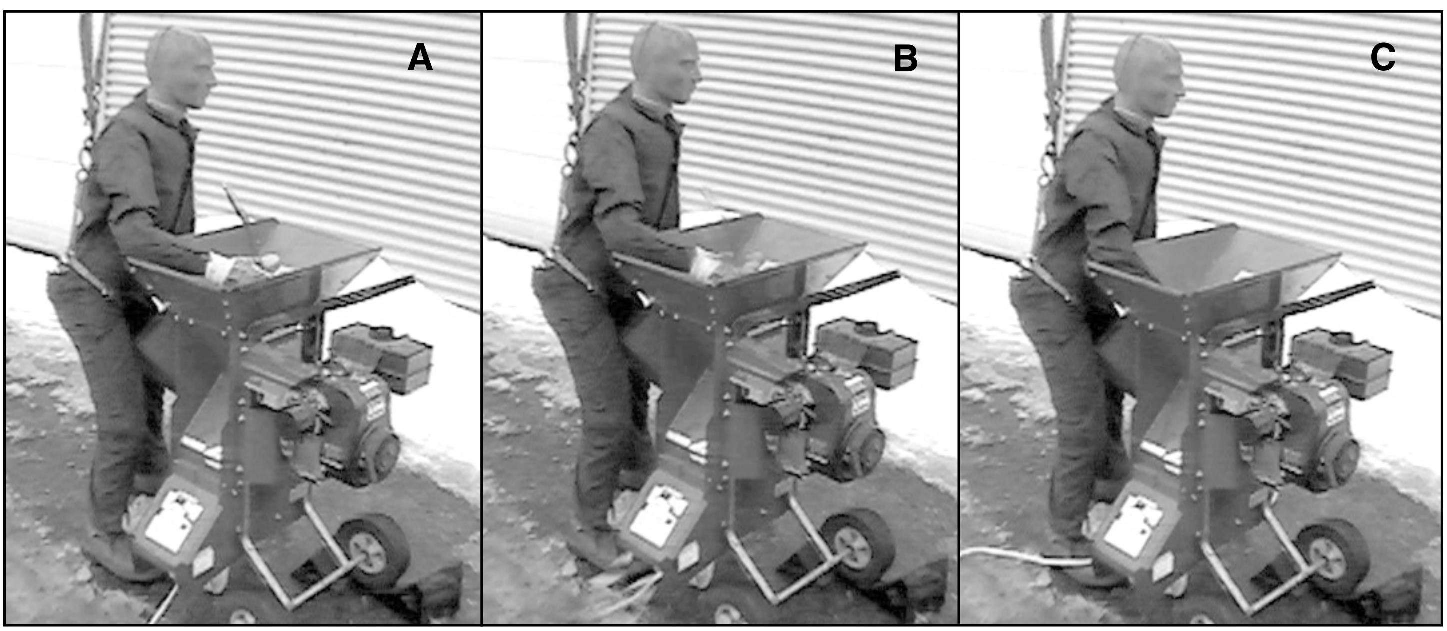
Table 2 - Static Test Results

Trial No.	Branch No.	Number of Nails	Connection Resistance (pounds)	Failure Mode
1	1	1	78.7	Branch pulled out of nail
2	1	1	86.0	Branch pulled out of nail
3	1	1	42.8	Branch pulled out of nail
4	1	2	122.0	Nails pulled out of glove
5	2	2	40.0	Branch pulled out of nails
6	3	2	32.0	Branch pulled out of nails
7	4	2	35.0	Branch pulled out of nails

Dynamic Testing

Using the test protocol, dynamic pull through tests were conducted on all four species' branches using single and double nailed joints into 1.27 cm (0.5 in.) diameter branches. In the first seven tests, the anthropomorphic dummy's elbow was bent and the gloved hand was located in the center of the top horizontal plane of the infeed hopper. Three additional tests were conducted with an extended arm dangling in a vertical attitude which brought the hand initially to the bottom of the infeed hopper.

In all ten tests, the joint was severed within 1/30 of a second (one video frame) after initiation of the pull. A typical test using a bent elbow produced the three frame sequence shown in Fig. 6. The first frame, 6A, defines the geometry just



A) Unloaded Arm *B) Severed Connection* *C) Final Arm Position*

Fig. 6 - Video Sequence - Snagged Glove with Bent Elbow

prior to loading; the second frame, 6B, represents the following video frame after the connection has been severed; frame 6C depicts the resting position after all motion has ceased. Figure 7 is a photograph of the final hand position. In all cases the downward shoulder movement was insignificant. Also, the bent arm was straightened with the hand remaining outside of the hammermill chamber. In addition to the two modes of failure observed in the static tests, the dynamic tests also included a case where the connection at the glove remained intact and the branch severed.

A typical pull through sequence associated with one of the three extended arm tests is depicted in Fig. 8. Once again, frame 8A illustrates the geometry immediately before loading; frame 8B is the video frame following the onset of loading; the final position after all motion has stopped is illustrated in frame 8C. Other than a small change in the hand configuration, the geometry of the anthropomorphic dummy was unaffected by the pull-in scenario. The hand remained outside the hammermill chamber in all three extended arm tests.

TESTING - TIED WRIST

Test Setup

Using garden jute twine tied around the wrist of an anthropomorphic dummy, three dynamic tests were conducted with an extended arm oriented vertically downward into the bottom of the infeed hopper. The position of the dummy followed the test protocol with one exception; twine was used instead of clothesline. Preceding the pull-in tests, a universal testing machine was used to determine the tenacity of 3 samples of the garden jute twine.

Fig. 7 - Final Hand Position - Snagged Glove with Bent Elbow

Test Results

Static testing provided three garden jute twine sample breaking strengths: 48 pounds, 62 pounds, and 59 pounds. Following these tests, the twine was wrapped and tied around a gloved hand as depicted in Fig. 9. The results of one of the three dynamic pull-in tests is characterized in Fig. 10. Frame 10A defines the geometry of the anthropomorphic dummy before loading occurred; the following frame, 10B, shows where the connection has been broken, and frame 10C shows the final geometry after cessation of motion. In two of the three tests, the twine failed at the knot; the twine fractured in the third test at an interior location. The resting position of the anthropomorphic dummy's hand in the test sequence is illustrated in Fig. 9 which is typical of all three dynamic twine tests. It should be noted that the hand never entered the hammermill chamber. This is consistent with the observation that the downward shoulder movement was imperceptible during the pull through scenario.

A) Unloaded Arm *B) Severed Connection* *C) Final Arm Position*

Figure 8 - Video Sequence - Snagged Glove with Extended Arm

CONCLUSIONS

1. If the shoulder does not move downward appreciably, an erectly standing operator's hand will not make contact with the flails.

2. For impulse testing performed under scenarios of snagging, entanglement, and friction grip, downward shoulder movement was insignificant.

3. The tensile integrity of the vegetation and its connection to the operator's hand must be sufficiently great that it will overcome the inertia of the upper torso before hand-flail contact occurs.

4. It is incumbent upon a technical investigator who formulates a chipper/shredder pull-in hypothesis to prove the hypothesis using testing, dynamic analysis, or computer simulation.

5. Manufacturers of consumer chipper/shredders have admonished users not to reach beyond certain benchmarks in the infeed hopper throat. Warnings and instructions of this type will preclude operators from reaching directly into the flails. Such warnings are a sensible way to control the hand-flail contact hazard.

REFERENCES

[1] Damon, A. et al., *The Human Body in Equipment Design*. Harvard University Press, Cambridge, MA 1966, pp. 72 - 73.

[2] Tilley, A. R., *The Measure of Man and Woman: Human Factors in Design.* The Whitney Library of Design, New York, 1993, pp. 11 & 13.

[3] *Anthropometry of Infants, Children, and Youths to Age 18 for Product Safety Design.* SP-450, SAE International, 1977, pp. 292 - 293.

[4] Barnett, R.L., and Brickman, D.B., "Chipper/Shredder: The Pull-in Hypothesis," *DETC 99/RSAFP-8868*, Proceedings of the 1999 ASME Design Engineering Technical Conferences, Las Vegas, NV, Sept. 12 - 15, 1999, pp. 1- 9.

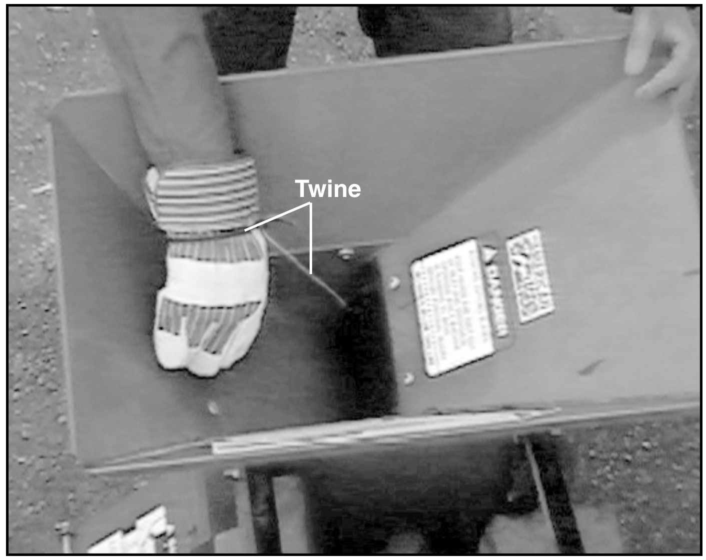


Fig. 9 - Final Hand Position - Tied Wrist

SAFETY BRIEF

August, 2001 – Volume 19, No. 2

Editor: Paula L. Barnett
Illustrated and Produced by
Triodyne Graphic Communication

Copyright © American Society of Mechanical Engineers (ASME). All Rights Reserved. No portion of this publication may be reproduced by any process without written permission of ASME. Questions pertaining to this publication should be directed to Triodyne, Inc., 5950 West Touhy Avenue, Niles, IL 60714-4610 (847) 677-4730. Direct all inquiries to: *Library Services.*

A) Unloaded Arm *B) Broken Connection* *C) Final Arm Position*

Figure 10 - Video Sequence - Tied Wrist