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SAFETY BRIEF

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The Meat Grinder Safety Throat†

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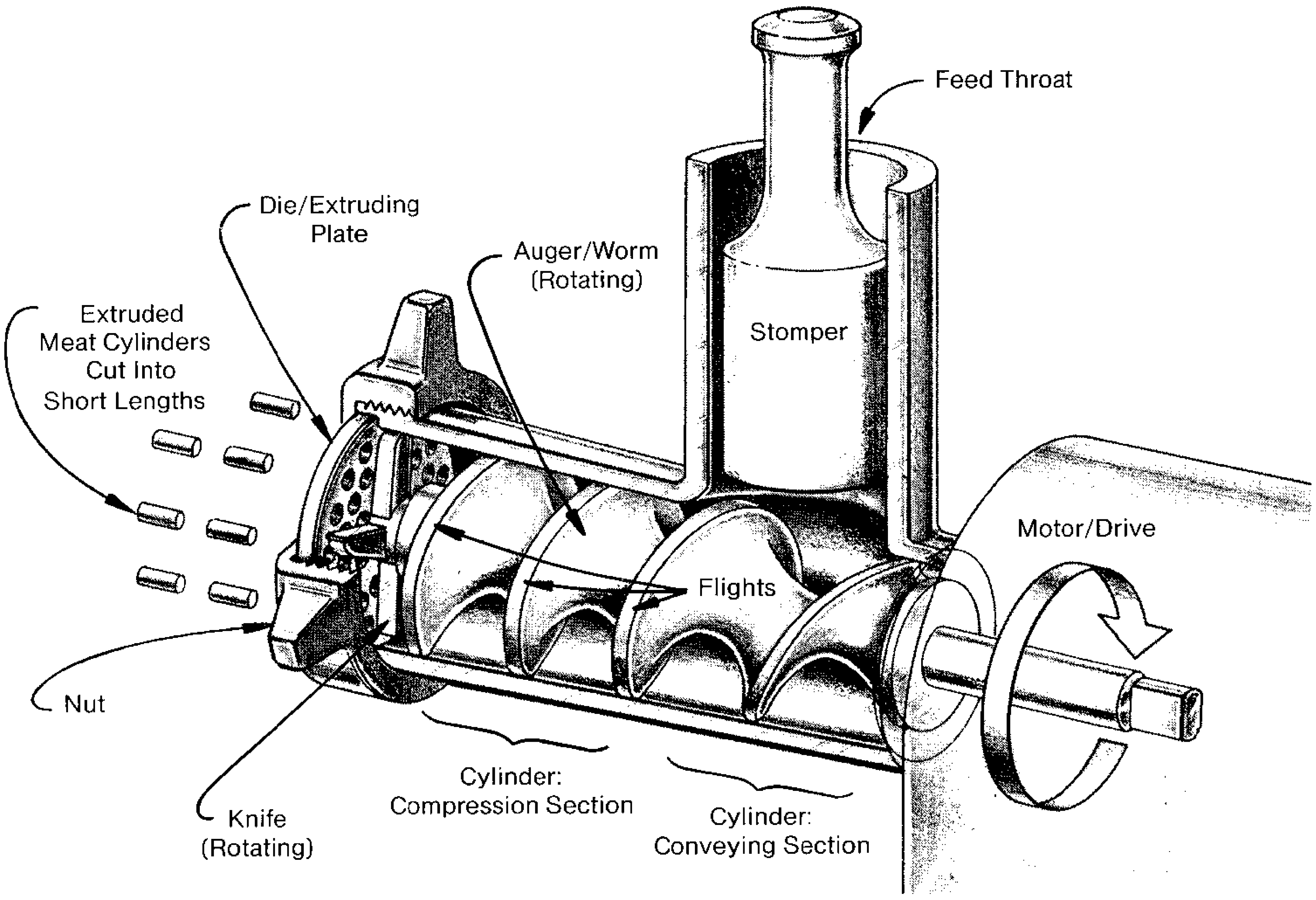
Abstract

Every engineered system represents a tradeoff among at least three criteria: cost, safety and function. For a meat grinder with a safety feed throat and stomper, common sense tells us that operator safety will increase as the throat diameter gets smaller and its length gets longer. It is just as apparent that the feed throat capacity will decrease accordingly. This paper quantifies the relationship among the throat parameters, the capacity and the stomper force.



▲ *Figure 1. Meat Grinder*

I. Introduction

The genesis of the modern meat grinder can be found in the patents of Shephard[4] and Brown[5]. Their original design was so functionally perfect that it hasn't changed in its concept or execution in almost 100 years. The components of the grinder are illustrated in Figure 1 where we can track its operation:

A. Food placed into the feed throat is dropped or tamped toward the auger.
B. The food commits to the auger by being insinuated between the rotating flights which convey it into the cylinder section.
C. The auger mixes and compresses the entrapped food and extrudes it through the holes in the die plate.
D. The resulting "spaghetti-like" cylinders of food are cut into short lengths before escaping the die by means of a four-blade knife rotating against the back of the die plate.

† This research was conducted for Triodyne Inc. by the Institute for Advanced Safety Studies.

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[4] Amos Shephard, U.S. 399,790. Filed August 1, 1888, issued March 19, 1889.

[5] John W. Brown, U.S. 424,758. Filed October 13, 1887, issued April 1, 1890.

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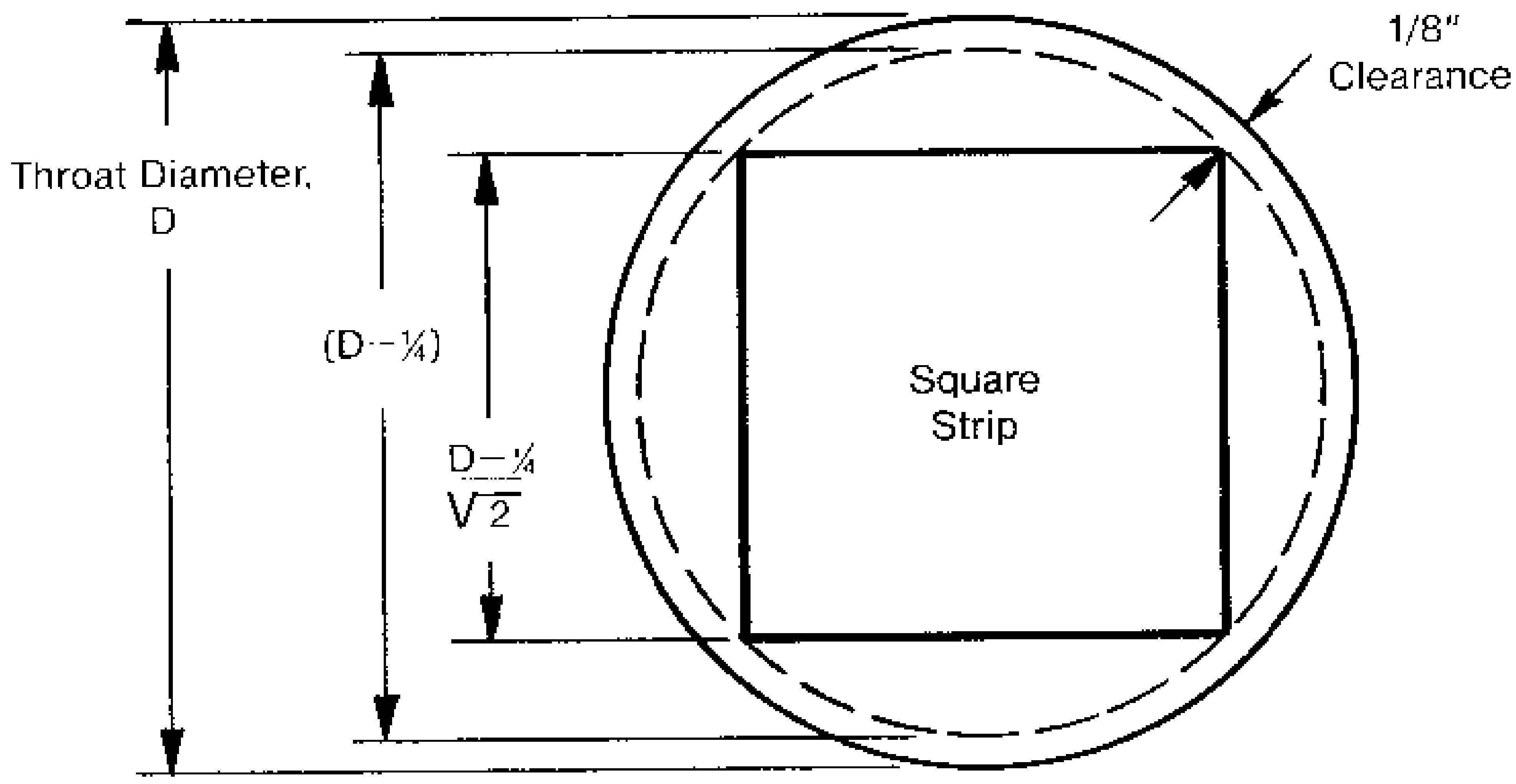
No Charge

A meat grinder converts large chunks of meat into thousands of short cylinders; it does not discriminate between a dead cow and a live hand. The resulting safety problem has been addressed by a number of safeguarding concepts. The most intriguing and controversial of these, the so-called "safety throat," is studied in this paper. It should be noted that the stomper is the primary point-of-operation safety device and that the safety throat is a secondary safety system which addresses those *misuse* scenarios where the stomper is not used and the hand is substituted.

When the safety throat was first introduced into the marketplace, the users were exclusively adult males. Accordingly, a feed tube diameter of 2½ inches and a length of 4½ inches were selected to prevent almost all users from contacting the auger or worm at the bottom of the feed tube.[6] It was fortuitous that these dimensions were compatible with the capacity expectations of commercial meat grinders. The development of fast food establishments radically impacted the original "safety throat" by introducing the 16-year-old female into the community of meat grinder operators.

The effectiveness of the safety throat is based entirely on anthropometric characteristics of the hand which directly relate to the user population. To provide equivalent misuse protection to 16-year-old females, manufacturers in this country reduced the meat grinder's safety throat diameter from 2½ inches to 2 inches and extended its length from 4½ inches to 6 inches. German meat grinders often use 2-inch diameter throats which are 8 inches in length. For non-commercial meat grinders used around children, throat diameters are often reduced to 1½ inches.

Table I—First Cut Throat Capacities—Ideal Square Strips



Safety Throat Diameter	Optimum Square Strip Dimensions	Area $\frac{(D-\frac{1}{4})^2}{2}$	Capacity Ranking
2½"	1.591" x 1.591"	2.531 in^2	100%
2"	1.237" x 1.237"	1.531 in^2	60.5%
1½"	0.884" x 0.884"	0.781 in^2	30.87%
1¼"	0.7071" x 0.7071"	0.500 in^2	19.76%

It obviously follows that the percentage of the population that can reach the grinder worm will decrease as the diameter of the safety throat is reduced and its length increased. It is equally obvious that the capacity of the feed throat will correspondingly decrease. Although it has received little attention, the stomper force must increase under the same conditions. This paper explores the relationships among safety throat parameters such as diameter, length, stomper force and meat characteristics.

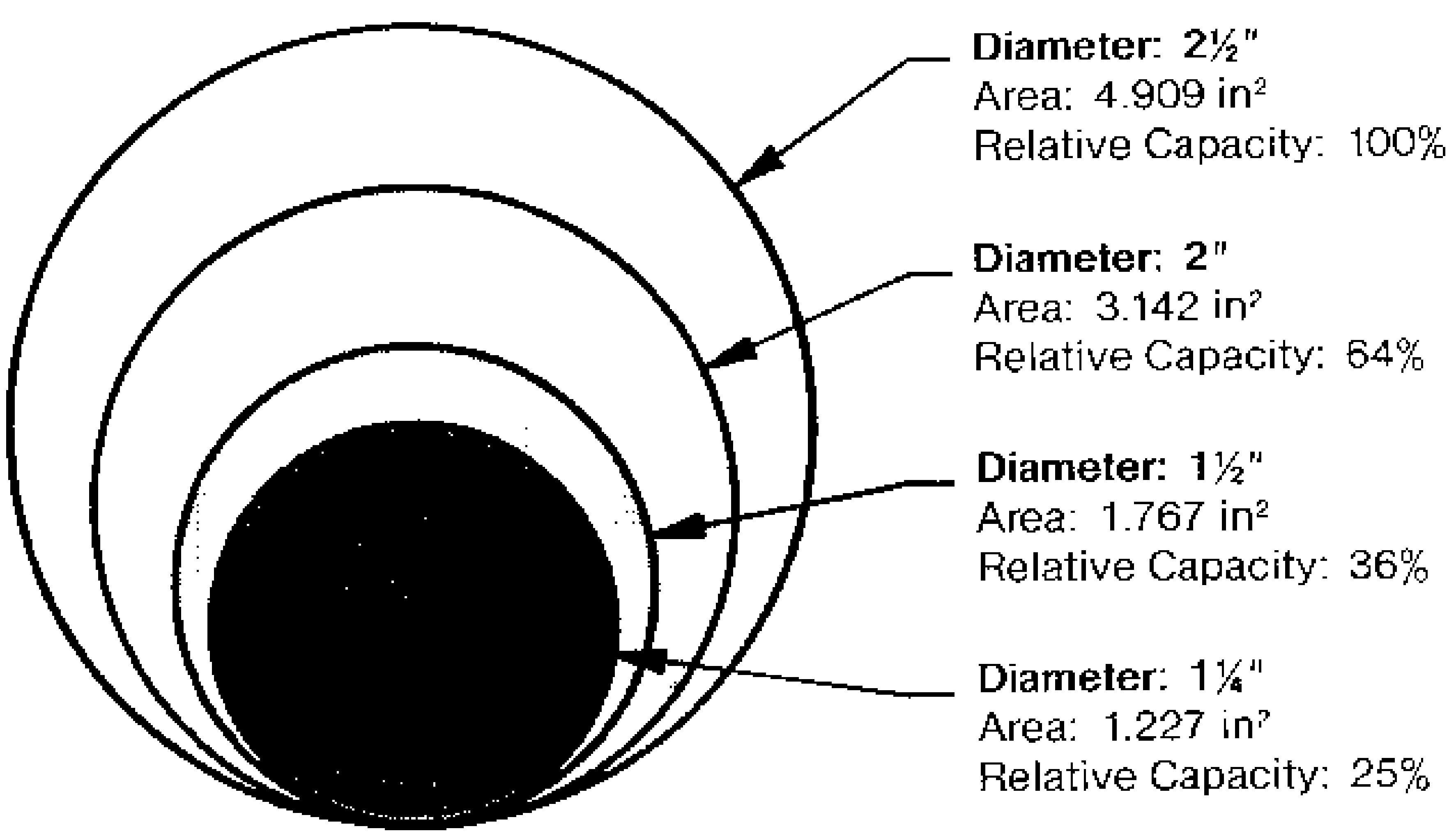
II. First-Cut Capacity

Hamburger is normally produced by passing meat through a meat grinder two times. The first pass is accomplished by feeding strips into the safety throat and allowing their ends to commit to the auger flights which pull them into the machine. The stomper is seldom used for the first cut.

To prepare the strips, large cuts of meat are sectioned using knives, cleavers, and hi-speed band saws. Although strips may be of any length, their maximum cross-sectional dimensions are, of course, dictated by the safety throat diameter D.

To develop an understanding of feed throat capacity it is useful to study two idealized situations; the optimum circular strip and the optimum square strip. If we assume it's possible to produce strips with circular cross sections*, we can maximize the feed throat capacity by literally keeping the "pipeline filled." Here, the safety throat capacity is directly proportional to its cross-sectional area. Figure 2 tabulates, displays and ranks various size feed throats. The capacity

▼ *Figure 2. First Cut Throat Capacities—Ideal Circular Strips*



[6]Regulations for Miscellaneous Hazards and Conditions of Employment. Harrisburg, Commonwealth of Pennsylvania, Department of Labor & Industry. "Rule 4. Meat Grinders" (2) originally approved Jan. 12, 1927, as amended through Oct. 15, 1956 and published in 1956 edition.

*(E.g., rolling thin slabs into cylinders, combining many long stringers or using a long circular cookie cutter.)

rankings are shown as a percentage of the area associated with the 2½-inch diameter throat. Notice that the capacity is dramatically compromised as the diameters get smaller. This simple but important observation is based on the fact that area varies as the "square of the throat diameter." Even though the diameter of the 2-inch tube is only 20% less than the 2½-inch tube, its area is 36% less.

The deterioration of the feed throat capacity becomes more profound when we study the more realistic case of the optimum square strip. Utilizing a wall clearance of ⅛ inch, Table 1 displays the side dimensions, the capacity (area) and the capacity ranking for various throat diameters. Here, the 2-inch tube capacity drops even more than 36% to 39.5% less than the capacity of the 2½-inch throat.

III. Second-Cut Capacity

The second-cut problem differs radically from the first-cut problem. Here, the meat has no pull strength (zero tensile strength) because it has been previously ground. Thus, unlike the strips, the auger cannot pull or draw the meat into its flights; it must fall or be pushed in. Under production conditions the meat is stuffed into the feed throat where it is urged downward with a stomper. The meat is forced against the sides of the feed throat and its movement is resisted by inertia, adhesion and friction.

The passage of the meat through the feed throat is studied in Appendix I using Newton's equation of motion. This equation takes account of the inertial resistance the meat offers to acceleration. The tendency of the meat to stick to the walls of the feed throat is included by introducing a resisting force which varies in proportion to the contact area between the meat and the wall. Finally, friction or drag resistance is incorporated in the motion equation using a resisting force that depends on how hard the meat pushes against the wall. This wall pressure is created when the stomper squeezes down on the meat and makes it try to expand (Poisson's ratio effect).

When all of the factors are taken into account we obtain a differential equation whose solution describes a relationship among the important meat grinding parameters: throat diameter (2r) and length (L), stomper force (F) and weight (W), capacity (C), and physical properties of meat such as its density (ρ), Poisson's ratio (μ), coefficient of friction (ν), and adhesive shear strength (τ). Two quite different meat grinding scenarios are studied in detail and are used to compare alternative safety throat diameters and lengths.

Table II—Stomper Forces—Replacement Feed Method

Safety Throat Dia x Lgth	Critical Community of Users	Threshold Force	Stomper Force: Men Using Wood Stompers	Stomper Force: Women Using Plastic Stompers
2½" x 4½"	Men	6 lbs	2 lbs	4 lbs
2" x 6"	Women	9 lbs	6 lbs	8 lbs
1½" x 8"	Children	23 lbs	24 lbs	24 lbs
1¼" x 8"	Infants	30 lbs	38 lbs	34 lbs

A. Replacement Feed Method

Meat may be introduced almost continuously into the feed throat by pushing the meat column downward only slightly and then refilling the vacancy with more meat. This *replacement method* effectively keeps the safety throat full during feeding which in turn produces a constant or unvarying resistance to the flow of meat.

This condition of constant resistance results in an equation called a linear ordinary differential equation with constant coefficients. The solutions for such equations are readily obtained and in the present case a formula is presented for the stomping force F where the feed throat is refilled every half second:

Equation A

$$F = \left[\frac{C\,(W + \pi r^2 \rho L)}{15\, g \pi r^2 \rho} + \left(\frac{1-\mu}{\mu} \right) \frac{\pi}{2\nu} \cdot \left(2r^2\tau - r^3\rho \right) \right] \exp\left[2\nu \left(\frac{\mu}{1-\mu} \right) \frac{L}{r} \right] - \left(\frac{1-\mu}{\mu} \right) \frac{\pi}{2\nu} \left(2r^2\tau - r^3\rho \right) - W$$

A rather complete exploration of this equation is presented in Table IV in the appendix. Highlights of interest to a general readership are described in Table II where the presentation is abbreviated and simplified. Here, four safety throats are listed in order of decreasing throat diameter and increasing length. Each is associated with a critical community of users selected subjectively. Anthropometric hand data and accident experience suggest, for example, that the 1¼"φ x 8"* throat will provide infants protection equivalent to that enjoyed by men using a 2½"φ x 4½" throat.

Equation A indicates a minimum stomper force required to begin the flow of meat. This has been tabulated in Table II under the column heading "Threshold Force" where we observe that the replacement feed scenario gives rise to unreasonably high stomper forces for safety throats that apply to children and infants; 23 lbs. and 30 lbs. respectively.

The last two columns of Table II show very large changes in the stomper force required as the safety throat decreases in diameter and increases in length. The reason that small changes in geometry give rise to large changes in stomper force is associated with the very sensitive exponential function represented by the symbol "e" in Equation A. As a practical observation, commercial safety throats cannot differ very much from the 2½"φ x 4½" throat dimensions and still retain a reasonable first-cut capacity and a sensible second-cut stomper force. It should be noted that the stomper forces shown in Table II do not include the weight of the stomper or the weight of the operator's arm; these amount to 4 lbs. for men with wood stompers and 2 lbs. for women with plastic stompers.

It may be observed from Table II that men must exert a 2-lb. stomping force when using the classical 2½"φ x 4½" feed throat with a wooden stomper. On the other hand, the 2"φ x 6" throat with the new plastic stomper offers women equivalent protection at the expense of a fourfold increase in stomper force to 8 pounds. When used continuously for second cutting, these high stomper forces may give rise to maladies such as Carpal Tunnel Syndrome.

Using Equation A, the stomper force F may be computed for various feed throat capacities C. The relationship between these quantities is displayed in Table III for a 2"φ x 6" throat and an effective *stomper + arm* weight of two pounds. We observe that very small changes in the stomper force produce very large changes in throat capacity; less than *1 lb.* increase in stomper force raises the capacity from 1 lb./min. to 50 lbs./min. Since any practical capacity can be achieved with stomper forces slightly greater than the threshold force (zero capacity), the second-cut capacity of a meat grinder will be governed primarily by the size and speed of its auger and not by its feed throat dimensions.

*φ . . . denotes diameter

Table III—Sensitivity of Capacity to Small Changes in Stomper Force*

Throat Capacity lbs/min	Stomper Force, F lbs
0	7.379
1	7.398
2	7.417
3	7.435
4	7.454
5	7.473
10	7.567
15	7.662
20	7.756
25	7.850
30	7.944
35	8.038
40	8.133
50	8.321
100	9.264

*W = 2 lbs

Throat: 2" Dia x 6" Lgth
$\mu = 0.35$, $\nu = 0.25$,
$\tau = 0.12$ psi, $\rho = 70$ lbs/ft^3

B. Full Plunge Feed Method

In contrast to the replacement feed method which keeps the throat full continuously, the *full plunge feed method* uses the stomper to evacuate completely a full feed throat. As the stomper moves downward, the resistance to the flow of meat falls off continuously. The mass and associated inertial resistance of the meat gets smaller and smaller as the auger removes the meat exiting the vertical throat. As the meat column decreases in height, the surface of the feed throat in contact with the meat also decreases and the corresponding frictional and adhesive resistances become less and less.

The behavior of the meat during the full plunge feed scenario is modeled mathematically in Appendix II where the equation of motion is found to be a nonlinear ordinary differential equation. Unlike the replacement feed analysis, the full plunge feed solution cannot be expressed as a "closed form" formula. Numerical analysis using a computer produced the required relationship between the stomper force and throat capacity. The results are displayed in Table V where the stomper forces are shown to be only slightly less than the corresponding forces in the replacement method.

The principal conclusion from this study is that widely varying feed scenarios produce the same result; hence, the previous observations made for the replacement feed method are valid generally for the second-cut problem.

IV. Conclusions and Observations

A. 2½"⌀ x 4½" Safety Throat

1. Very few injuries to adult males have been reported for this classical feed tube. On the other hand, many women and almost all children can reach the auger through this safety throat.
2. The total downward force required to begin movement or flow of ground meat in a fully loaded feed tube is called the threshold force. Here, it is calculated as 5.65 pounds for hamburger characterized as "Primary source chuck and other lean cuts."
3. Almost any practical feed capacity can be obtained with a total force only slightly higher than the threshold force. For example, an additional force of only 0.05 pounds will increase the flow rate from zero to 25 lbs./min.
4. An adult male using a wood stomper must exert less than 2 pounds of stomper force for second cutting; women require 4 pounds because their effective arm weight is two pounds less.

B. 2"⌀ x 6" Safety Throat

1. This feed tube offers women protection equivalent to that enjoyed by men using a 2½"⌀ x 4½" safety throat. Children, unfortunately, can usually reach the auger without difficulty.
2. The first-cut capacity of the 2"⌀ x 6" throat is just about 40% less than the 2½"⌀ x 4½" feed throat.
3. When using a plastic stomper, women must exert about 8 pounds for second cutting. Stomper forces of this magnitude are fatiguing and may lead to ailments such as Carpal Tunnel Syndrome.
4. This feed throat represents just about the maximum practical deviation from the classical 2½"⌀ x 4½" throat. Moving to a 1½" diameter throat reduces the first-cut capacity by 70%. Extending the length to eight inches raises the stomper force required to an outrageous 18 pounds.

C. The safety throat candidates that hold promise for protecting children and infants have absolutely none of the required commercial capabilities.

D. There is a special misuse scenario associated with the *full plunge* feed method where the risk grows with increasing threshold force. Here, the throat is hand-fed by members of the population with small hands that can reach the auger. As the high initial resisting forces rapidly drop off, the hand is driven into the worm before it can be stopped or withdrawn. (See Appendix II.)

E. The second-cut capacity of a meat grinder is mostly limited by the size and RPM of the auger and not the feed throat.

F. Widely varying feeding programs for second cutting produce very similar *stomper force/capacity* relationships.

G. The mass of the stomper and arm become significant variables only in the smaller tubes where the flow velocity must necessarily be greater to provide equivalent capacity.

H. The stomper force required grows very rapidly with increasing feed tube length.

Index to the Triodyne Safety Brief

A comprehensive index for the first three volumes of the *Triodyne Safety Brief* has been compiled and is available for readers who wish to receive a complimentary copy.

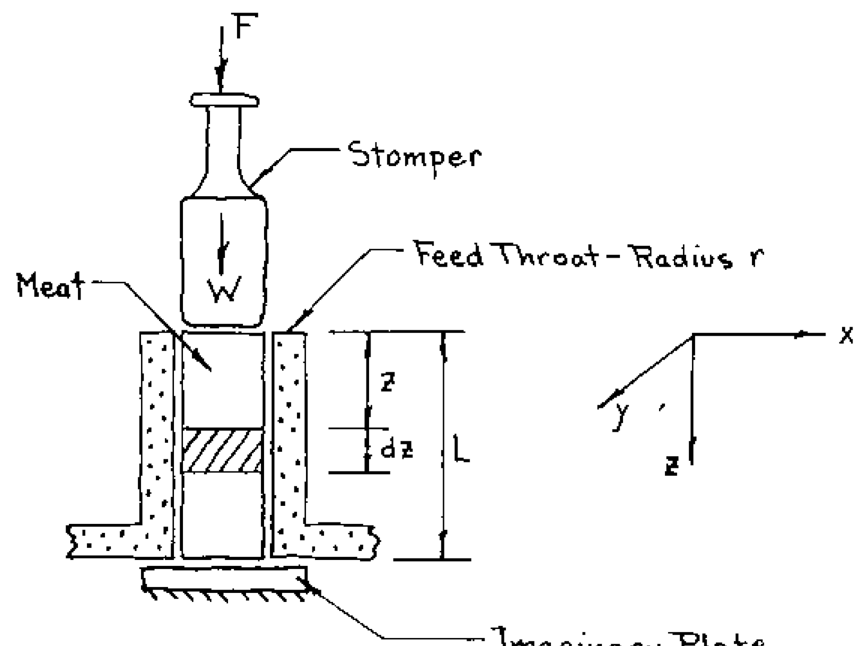
Vol. 1 No. 1 On the Classification of Safety Devices—Intrinsic System
No. 2 On the Classification of Safety Devices—Functional Hierarchy
No. 3 Z.O.R.O. Zero Obstruction Repair Overpass
No. 4 Philosophical Aspects of Dangerous Safety Systems

Vol. 2 No. 1 On Safety Codes and Standards
No. 2 Safety and Product Liability Considerations in Farm Machinery Equipment
No. 3 The Dependency Hypothesis—Misuse
No. 4 On the Safety of Motorcycle Side Stands

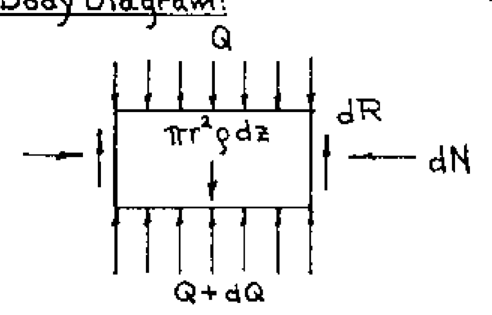
Vol. 3 No. 1 The Dependency Hypothesis—Expected Use
No. 2 Safety Hierarchy
No. 3 Trailer Hitches and Towbars
No. 4 The Meat Grinder Safety Throat

Volume 4, now in preparation, will include Punch Press Safety Bibliography

Appendix I
Replacement Feed Method



Free Body Diagram:



Vertical Equilibrium:

1) $Q + dQ + dR - \pi r^2 \rho \, dz - Q = 0$

where: Q... force acting on section z

R... resistance due to friction and adhesion

ρ... meat density (weight/unit volume)

Adhesive Resistance: dR_1

Taking dR_1 as a resistance which is proportional to the contact area between the meat and the wall,

2) $dR_1 = (2\pi r \, dz)\tau$

where τ is the shear resistance at the meat/wall interface.

Frictional Resistance: dR_2

The frictional resistance dR_2 is equal to the product of the normal force dN and the coefficient of friction ν. The normal force can be established by observing that the meat cannot expand laterally in the tube, $\epsilon_x = 0$. Hooke's Law provides a relationship between the lateral and vertical stresses;

3) $\epsilon_x = \frac{\sigma_x}{E} - \frac{\mu}{E}(\sigma_y + \sigma_z) = 0$

Because of symmetry, the only in-plane forces that can act on the meat slice are the radial forces dN. This loading leads to an isotropic in-plane stress state, i.e.,

4) $\sigma_x = \sigma_y$

The vertical stress σ_z is given by

5) $\sigma_z = \frac{-Q}{\pi r^2}$

Substituting Eqvs.(4) and (5) into Eq.(3) we obtain,

6) $\sigma_x = -\frac{Q}{\pi r^2}\left(\frac{\mu}{1-\mu}\right)$

Since the normal force is

7) $dN = (2\pi r \, dz)(-\sigma_x)$,

we obtain the frictional resistance using Eqs.(6) and (7);

8) $dR_2 = \frac{2Q\nu}{r}\left(\frac{\mu}{1-\mu}\right)dz$

Thus, the combined resistance dR is found from Eqvs.(2) and (8),

9) $dR = 2\pi r \tau \, dz + \frac{2Q\nu}{r}\left(\frac{\mu}{1-\mu}\right)dz$

Substituting dR into the equilibrium equation, Eq.(1), and dividing by dz we obtain,

10) $\frac{dQ}{dz} + \frac{2\nu}{r}\left(\frac{\mu}{1-\mu}\right)Q + (2\pi r \tau - \pi r^2 \rho) = 0$

The general solution of this linear differential equation may be found in the usual manner by taking the complementary function in the form

11) $Q = ke^{nz}$

and the particular integral in the form

12) $Q = c$

where k, n and c are constants. Using the boundary condition,

13) $Q = F + W$ at $z = 0$

we obtain the solution for Q where F is the stomper force and W is the effective weight of the stomper and operator's arm.

14) $$Q = \left[F + W + \left(\frac{1-\mu}{\mu}\right)\frac{\pi}{2\nu}(2r^2\tau - r^3\rho)\right]\exp\left[\frac{-2\nu}{r}\left(\frac{\mu}{1-\mu}\right)z\right] - \left(\frac{1-\mu}{\mu}\right)\frac{\pi}{2\nu}(2r^2\tau - r^3\rho)$$

The gravity forces acting on the meat column within the feed throat are resisted by wall friction, wall shear and by the reactive force of the imaginary plate, Q(L), at the bottom of the meat column. If the imaginary plate is removed, the meat column, stomper and operator's arm will begin to accelerate under the unbalanced force Q(L). The equation of motion in the vertical direction may be written

15) $\left(\frac{W + \pi r^2 L \rho}{g}\right) a = Q(L)$

where $\underline{a}$ is the vertical acceleration. Under a constant acceleration $\underline{a}$ the meat column will travel a distance $\frac{1}{2}at^2$ where t is the replacement time interval. In a half second the meat passing through the feed throat will weigh $\pi r^2 a \rho / 8$. The feed throat capacity C in pounds per minute is 120 times this quantity or

16) $C = 15\pi r^2 \rho a$ (@ t = ½ sec)

Substituting Eq.(14) into Eq.(15) and eliminating $\underline{a}$ between Eqs.(15) and (16), we obtain Eq.(A) for the stomper force F.

Table IV displays the stomper forces for various capacities and stomper/arm weight combinations W. The figures were calculated from Eq.(A) using meat parameters obtained for ground meat characterized as "Primary Source Chuck, and other lean cuts."

Table IV—Stomper Force, F—Replacement Feed Method

Dia x Lgth:	Stomper + Arm Wt	Capacity: Zero (Incipient Motion)	Capacity: 15 lbs/min	Capacity: 25 lbs/min
2½" x 4½":	W = 0	5.6484 lbs*	5.6791 lbs	5.6996 lbs
	W = 2 lbs	3.6484 lbs	3.7478 lbs	3.8140 lbs
	W = 4 lbs	1.6484 lbs	1.8164 lbs	1.9284 lbs
2½" x 6":	W = 0	9.1194 lbs*	9.1759 lbs	9.2136 lbs
	W = 2 lbs	7.1194 lbs	7.2707 lbs	7.3716 lbs
	W = 4 lbs	5.1194 lbs	5.3655 lbs	5.5296 lbs
2" x 6":	W = 0	9.3811 lbs*	9.4592 lbs	9.5113 lbs
	W = 2 lbs	7.3811 lbs	7.6638 lbs	7.8523 lbs
	W = 4 lbs	5.3811 lbs	5.8684 lbs	6.1933 lbs
2" x 8":	W = 0	17.7340 lbs*	17.9124 lbs	18.0313 lbs
	W = 2 lbs	15.7340 lbs	16.2630 lbs	16.61[illegible]6 lbs
	W = 4 lbs	13.7340 lbs	14.6136 lbs	15.1999 lbs
1½" x 6":	W = 0	10.4816 lbs*	10.6154 lbs	10.7046 lbs
	W = 2 lbs	8.4816 lbs	9.2387 lbs	9.7434 lbs
	W = 4 lbs	6.4816 lbs	7.8619 lbs	8.7822 lbs
1½" x 8":	W = 0	22.9346 lbs*	23.3004 lbs	23.5443 lbs
	W = 2 lbs	20.9346 lbs	22.5783 lbs	23.6740 lbs
	W = 4 lbs	18.9346 lbs	21.8561 lbs	23.8037 lbs
1¼" x 6":	W = 0	11.9955 lbs*	12.2014 lbs	12.3386 lbs
	W = 2 lbs	9.9955 lbs	11.5821 lbs	12.6398 lbs
	W = 4 lbs	7.9955 lbs	10.9628 lbs	12.9411 lbs
1¼" x 8":	W = 0	29.7284 lbs*	30.3781 lbs	30.8112 lbs
	W = 2 lbs	27.7284 lbs	31.6460 lbs	34.2578 lbs
	W = 4 lbs	25.7284 lbs	32.9140 lbs	37.7043 lbs

*Threshold Forces

Poisson's Ratio, $\mu = 0.35$

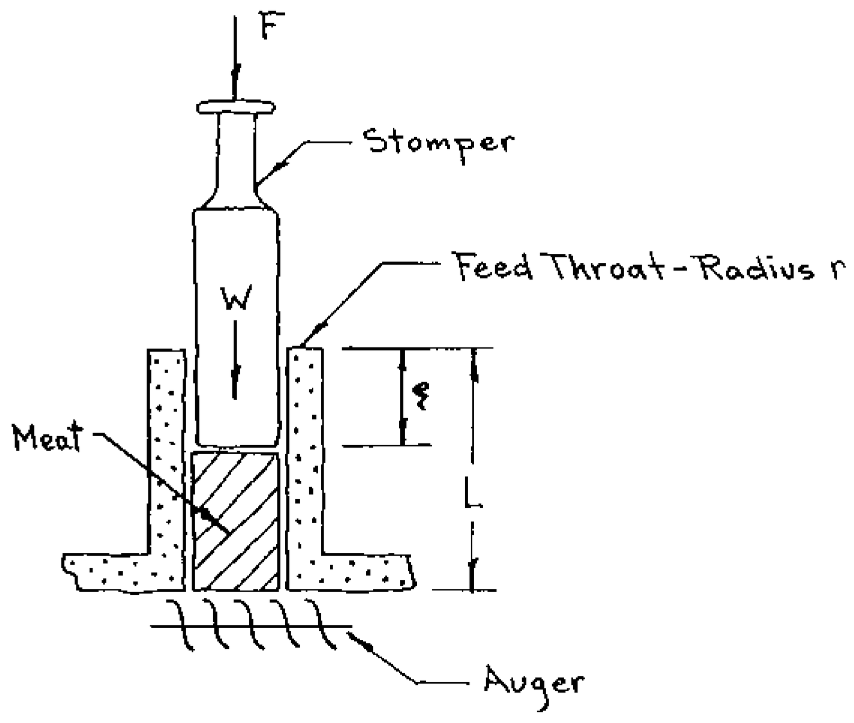
Coefficient of Friction, $\nu = 0.25$

Adhesive Shear Strength, $\tau = 0.12$ psi

Weight Density, $\rho = 0.0405$ lbs/in³ = 70 lbs/ft³

Replacement Interval, t = ½ sec.

Appendix II
Full Plunge Feed Method



Equation of Motion:

In the full plunge feed method it is assumed that the auger removes the meat as fast as it exits the feed tube. When the stomper has moved a distance ξ into the throat, the height of the meat column is $L-\xi$ and its acceleration may be expressed as the second derivative of ξ with respect to time. Thus, the equation of motion for this case requires that Eq.(15) be rewritten with L replaced by $L-\xi$,

$$17)\quad \left[\frac{W+(L-\xi)\pi r^2\rho}{g}\right]\ddot{\xi} = \left[W+F+\left(\frac{1-\mu}{\mu}\right)\frac{\pi}{2\nu}\left(2r^2\tau - r^3\rho\right)\right]\cdot \exp\left[-2\nu\left(\frac{\mu}{1-\mu}\right)\left(\frac{L-\xi}{r}\right)\right] - \left(\frac{1-\mu}{\mu}\right)\frac{\pi}{2\nu}\left(2r^2\tau - r^3\rho\right)$$

This equation may be rewritten as

$$18)\quad A\ddot{\xi} - B\xi\ddot{\xi} - Ce^{-D+H\xi} + G = 0$$

where

$$19)\quad \begin{cases} A \equiv (W+L\pi r^2\rho)/g \\ B \equiv \pi r^2\rho/g \\ C \equiv W+F+\left(\frac{1-\mu}{\mu}\right)\frac{\pi}{2\nu}\left(2r^2\tau - r^3\rho\right) \\ D \equiv 2\nu\left(\frac{\mu}{1-\mu}\right)\frac{L}{r} \\ H \equiv D/L \\ G \equiv \left(\frac{1-\mu}{\mu}\right)\frac{\pi}{2\nu}\left(2r^2\tau - r^3\rho\right) \end{cases}$$

Equation (18) is a second order non-linear differential equation in which time does not appear explicitly. Such equations may be solved by integration when we write

$$20)\quad \upsilon = \frac{d\xi}{dt}$$

Then,

$$21)\quad \frac{d^2\xi}{dt^2} = \frac{d\upsilon}{dt} = \frac{d\upsilon}{d\xi}\frac{d\xi}{dt} = \upsilon\frac{d\upsilon}{d\xi}$$

Using Eqs.(20) and (21), Eq.(18) becomes

$$22)\quad A\upsilon\frac{d\upsilon}{d\xi} - B\xi\upsilon\frac{d\upsilon}{d\xi} - Ce^{-D+H\xi} + G = 0$$

Separation of variables yields

$$23)\quad \upsilon\, d\upsilon = \frac{Ce^{-D+H\xi} - G}{A - B\xi}\, d\xi$$

After integration we obtain

$$24)\quad \upsilon = \left(2\int_0^{\xi}\frac{Ce^{-D+H\beta} - G}{A - B\beta}\, d\beta + k_1\right)^{1/2}$$

where k_1 is a constant of integration and β is a dummy variable.

Using Eq.(20) in Eq.(24) and separating variables we obtain

$$25)\quad dt = \frac{d\xi}{\left(2\int_0^{\xi}\frac{Ce^{-D+H\beta} - G}{A - B\beta}\, d\beta + k_1\right)^{1/2}}$$

Further integration produces

$$26)\quad t = \int_{\alpha=0}^{\alpha=\xi}\frac{d\alpha}{\sqrt{\frac{2G}{B}\ln\left(\frac{A-B\alpha}{A}\right) + 2Ce^{-D}\int_0^{\alpha}\frac{e^{H\beta}}{A-B\beta}\, d\beta + k_1}} + k_2$$

where k_2 is a second arbitrary constant and α is a dummy variable. Imposing the boundary conditions

$$27)\quad \xi = 0 \text{ and } \upsilon = 0 \text{ at } t = 0,$$

we find that $k_1 = k_2 = 0$.

The total time required to evacuate the feed tube, t^*, is found by taking $\xi = L$ in Eq.(26). Thus,

$$t^* = \int_0^L \frac{\sqrt{B/2}\, d\alpha}{\sqrt{G\ln\left(\frac{A-B\alpha}{A}\right) - Ce^{\left(\frac{AH}{B}-D\right)}\left[\ln|\gamma| + \frac{\gamma}{1\cdot 1!} + \frac{\gamma^2}{2\cdot 2!} + \cdots\right]_{-\frac{AH}{B}}^{-\frac{AH}{B}+H\alpha}}} \quad \ldots \text{Eq.(28)}$$

Using numerical integration methods, t^* was calculated and used to establish the associated feed throat capacity,

$$29)\quad \text{Cap.} = L\pi r^2\rho/t^*$$

The results are displayed in Table V for various feed throat candidates.

Uncontrolled Motion:

It should be noted that the initial physical conditions for both the replacement feed method and the full plunge feed method are identical. Consequently, the threshold forces are the same. Recall that the threshold force is associated with zero capacity and accordingly zero acceleration.

An analysis of Tables IV and V indicates that all practical capacities can be achieved using stomper forces that differ very slightly from the threshold forces. It may therefore be concluded that the initial accelerations of the meat through the feed throats are approximately zero. On the other hand, the final accelerations in the full plunge feed method can be quite high since the mass of the meat disappears together with the frictional and adhesive resistance. Taking $\xi = L$ in Eq.(17) we find the final acceleration to be

$$30)\quad \ddot{\xi}(L) = g\left(1 + \frac{F}{W}\right).$$

Table V, for example, gives a ratio $F/W = 3.68$ for a 2"ø × 6" feed throat at a capacity of 25 lbs/min. Here, the final acceleration is almost five times the gravitational acceleration g, i.e.,

$$31)\quad \ddot{\xi}(L) = 4.68\, g$$

The safety implication of these observations apply to those members of the population who can reach through the safety throats. If they attempt to push the meat by hand, they will experience a rapid increase in acceleration from about zero to very high values. This may lead to uncontrolled hand motions directed toward the auger.

Table V—Stomper Force, F—Full Plunge Feed Method

Dia x Lgth:	Stomper + Arm Wt	Capacity: 15 lbs/min	Capacity: 25 lbs/min
2½" x 4½":	W = 2 lbs	3.64118 lbs	3.64137 lbs
	W = 4 lbs	1.64124 lbs	1.64163 lbs
2½" x 6":	W = 2 lbs	7.10594 lbs	7.10613 lbs
	W = 4 lbs	5.10601 lbs	5.10636 lbs
2" x 6":	W = 2 lbs	7.36563 lbs	7.36636 lbs
	W = 4 lbs	5.36589 lbs	5.36753 lbs
2" x 8":	W = 2 lbs	15.69834 lbs	15.69919 lbs
	W = 4 lbs	13.69862 lbs	13.70031 lbs
1½" x 6":	W = 2 lbs	8.46240 lbs	8.47015 lbs
	W = 4 lbs	6.46743 lbs	6.57268 lbs
1½" x 8":	W = 2 lbs	20.87555 lbs	20.88323 lbs
	W = 4 lbs	18.8848 lbs	18.9479 lbs
1¼" x 6":	W = 2 lbs	9.9824 lbs	10.2266 lbs
	W = 4 lbs	8.0527 lbs	9.0617 lbs
1¼" x 8":	W = 2 lbs	27.6588 lbs	27.8303 lbs
	W = 4 lbs	25.7065 lbs	26.5961 lbs

Poisson's Ratio, $\mu = 0.35$
Coefficient of Friction, $\nu = 0.25$

Adhesive Shear Strength, $\tau = 0.12$ psi
Weight Density, $\rho = 0.0405$ lbs/in^3 $= 70$ lbs/ft^3

What is a Defect?

The current definition of a defective product in each state may be found in the case law of that state. Triodyne Inc. relies on the trial bar for the selection of the leading court decisions. Each month we will continue our exploration of the leading product liability case law in the United States.

Florida

West v. Caterpillar Tractor Company [336 SO 2d.80 (1976)]

A Caterpillar grader, operated in reverse by a road construction employee of Houdaille Industries, ran over Gwendolyn West. Ms. West died of massive internal injuries. Ms. West's husband and her estate claimed a right to damages against Houdaille and Caterpillar. He settled with Houdaille and brought a products liability suit against Caterpillar. His complaint contained two counts: (1) Negligent design by failure to provide adequate rear-view mirrors, manufacturing a grader with a blind spot created by obstructions when looking in the rear-view mirror while driving in reverse and (2) breach of implied warranty or strict liability based on the above design defects.

On appeal the Supreme Court of Florida considered the following:

"Questions to be Certified.

"1. (a) Under Florida law, may a manufacturer be held liable under the theory of strict liability in tort, as distinct from breach of implied warranty of merchantability, for injury to a user of the product or a bystander?

"(b) If the answer to 1(a) is in the affirmative, what type of conduct by the injured party would create a defense of contributory or comparative negligence?

"(1) In particular, under principles of Florida law, would lack of ordinary due care, as found by the jury in this case, constitute a defense to strict tort liability?

"2. Assuming Florida law provides for liability on behalf of a manufacturer to a user or bystander for breach of implied warranty, what type of conduct by an injured person would constitute a defense of contributory or comparative negligence?

"(a) In particular, does the lack of ordinary due care, as found by the jury in the case, constitute such a defense?"

The court answered these questions as follows:

"...strict liability should be impressed only when a product the manufacturer places on the market, knowing that it is to be used without inspection for defects, proves to have a defect that causes injury to a human being...In order to hold a manufacturer liable on the theory of strict liability in tort, the user must establish the manufacturer's relationship to the product in question, the defect and unreasonably dangerous condition of the product, and the existence of the proximate causal connection between such condition and the user's injuries or damages.

"We adopt the doctrine of strict liability as stated by the A.L.I. Restatement (Second) of Torts §402A.[1]

"Even though the Restatement §402A and the U.C.C. (Uniform Commercial Code) provide conflicting products liability rules, that fact alone does not establish that a Court in a U.C.C. jurisdiction that followed the Restatement §402A would be improperly ignoring a legislative enactment. ...The doctrine of strict liability does not introduce a notion of 'defective condition unreasonably dangerous to the user or consumer or to his property' which is different from the notion of 'unmerchantability' as applied in warranty law...the strict liability doctrine adapts the law to the marketing condition of today's marketing consumer...At the present time there is no legislative impediment to the adoption of this doctrine.

"We now hold that a manufacturer may be held liable under the theory of strict liability in tort, as distinct from breach of implied warranty of merchantability, for injury to a user of the product or a bystander, thereby answering question 1(a) in the affirmative.

"...Contributory negligence is not a defense in a strict liability action... if such a defense is based upon the failure of the user to discover the defect in the product or the failure of the user to guard against the possibility of its existence.

"Contributory negligence of the consumer or user by unreasonable use of a product after discovery of the defect and the danger is a valid defense.

"The adoption of the doctrine of strict liability in tort does not result in the demise of implied warranty. If a user is injured by a defective product, but the circumstances do not create a contractual relationship with a manufacturer, then the vehicle for recovery could be strict liability in tort. If there is a contractual relationship with the manufacturer, the vehicle of implied warranty remains...

"Unreasonable exposure to a known and appreciated risk should bar recovery in an action based upon implied warranty just as it bars recovery in negligence. However, it is unreasonable to require the noncommercial consumer to make any sort of detailed or expert inspection. If the injured person's conduct is a proximate cause of the injuries, the defendant would have the right to a charge on comparative negligence in an action for breach of implied warranty. If the injured person failed to use that degree of care which a reasonable careful person would use under like circumstances than he is guilty of some negligence. If this negligence was a proximate contributing cause of the injuries, the defendant would be entitled to raise the defense of contributory or comparative negligence. In other words, lack of ordinary due care could constitute such a defense."

Case selected by: Fred Mattlin of Siemon, Larsen & Mattlin, 1900 Glades Road, Boca Raton, FL 33431.

[1] "(1) One who sells any product in a defective condition unreasonably dangerous to the user or consumer or to his property is subject to liability for physical harm thereby caused to the ultimate user or consumer, or to his property, if

"(a) the seller is engaged in the business of selling such a product, and

"(b) it is expected to and does reach the user or consumer without substantial change in the condition in which it is sold.

"(2) The rule stated in Subsection (1) applies although

"(a) the seller has exercised all possible care in the preparation and sale of his product, and

"(b) the user or consumer has not bought the product from or entered into any contractual relation with the seller."

Georgia

Parzini v. Center Chemical Company [136 Ga. App 396 (1975)]

Mr. Parzini, a restaurant employee, tried to open a bottle of drain cleaner manufactured by Center Chemical. The drain cleaner was almost pure sulfuric acid and was packaged in a plastic bottle flexible enough to yield to a firm hand grip. The top of the bottle was machine-tightened and Mr. Parzini was unable to remove it. Another employee was also unable to remove the top. The two men got pliers and Parzini held the bottle while the other man used the pliers to unscrew the top. When the top came off the liquid squirted into the air and fell on Parzini's head, burning and blinding him.

Georgia Code §105-106 deals with the liability of manufacturers of personal property in the state:

> "However, the manufacturer of any personal property sold as new property, either directly or through a dealer or any other person, shall be liable in tort, irrespective of privity, to any natural person who may use, consume or reasonably be affected by the property and who suffers injury to his person or property because the property when sold by the manufacturer was not merchantable and reasonably suited to the use intended and its condition when sold is the proximate cause of the injury sustained; a manufacturer may not exclude or limit the operation hereof."

The Georgia Supreme Court ruled that the trial court had erroneously restricted the case to negligence when it should have been submitted to the jury on the theory of strict liability in tort:

> "We hold further that the claimant is not required to prove negligence under Code Ann. §105-106...All of the authorities supporting the doctrine of strict liability in tort have recognized the necessity that the plaintiff establish that there was a 'defect' in the defendant's product... We construe...Code Ann. §105-106 to mean that the plaintiff must show that the manufacturer's product when sold by the manufacturer was defective...Under Code Ann. §105-106 the question is whether the product was defective in its manufacture, its packaging, or the failure to adequately warn of its dangerous properties...'No reason is apparent for distinguishing between the product itself and the container in which it was supplied; and the two are purchased by the user or consumer as an integrated whole.'"

The court also ruled that if consumers discover defects and are aware of danger but proceed unreasonably to use the product, they are barred from recovery.

When the case was returned to the court of appeals the Supreme Court's rules were applied:

> "The jury is first to determine whether the product was defective. In this it has for consideration the manufacture, the packaging, and the warnings connected with its use. If the jury finds the product defective, it next considers whether the user knew of the defect and danger and whether his use of the product in view of this knowledge was unreasonable. If so, the plaintiff may not recover on this legal theory. Thus, contributory negligence applies to the negligence theory of action, whereas assumption of risk applies to the strict liability theory."

Case selected by: Paul W. Painter of Karsman, Brooks & Painter, P.O. Box 9149, Savannah, GA 31412.

SAFETY BRIEF

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