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Evaluation of Chain Saw Simulated Kickback Modes

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Manufacturing Engineering
Washington, DC 20234

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Report to:
Consumer Product Safety Commission
Bethesda, MD 20016

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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Abstract

For the past several years, NBS has supported the Consumer Product Safety Commission (CPSC) in the development of a performance standard to address the kickback hazard for chain saws. This process included participation of the Chain Saw Manufacturers Association (CSMA), CPSC, and NBS in the development of kickback testing equipment and procedures and the study of operator/saw interactions during simulated kickback trials. The present report describes an evaluation of the CSMA and CPSC procedures for simulating "Classical" or rotational kickback motion based primarily on analyses of high-speed films of simulated kickback trials, the development of test procedures for simulating "pinch" or linear kickback motion, and the simulation of kickback for the actuation of chain brake systems for chain saws. Included in the report is a discussion of important kickback test parameters such as mechanical energy, saw inertia, handle spacing and the interrelationships among the various kickback parameters.

I. Introduction

For the last several years, the National Bureau of Standards (NBS) has supported the Consumer Product Safety Commission (CPSC) in the development of a performance standard to address the kickback hazard for chain saws. This process has led to the participation of the Chain Saw Manufacturers' Association (CSMA), the Commission, and NBS in the development of kickback testing equipment and procedures, study of operator/saw interactions, and analysis of injury data.*

A kickback test machine (KBM) was adapted so that test procedures could be developed for assessing the kickback energy potential of chain saws. A report describing the exploratory chain saw research at NBS in this joint effort with the Commission and the chain saw industry is given in Reference [1]. An experimental program was then developed at NBS to determine the relationship between kickback energy and chain saw motion during hand-held kickbacks (i.e., for saws held by volunteer test subjects) for selected samples of consumer-type chain saws and various test subjects [2]. The present report describes an evaluation of the Association and Commission procedures for simulating "classical" or rotational kickback motion based primarily on analyses of high-speed movies, the development of test procedures for simulating "pinch" or linear kickback motion, and the simulation of kickbacks for the actuation of chain brake systems of chain saws. Included in the report is a discussion of the advantages and disadvantages of the rotational kickback simulations which were used by the Association and the Commission.

Since the report is organized to distinguish between two principal modes of kickback motion, it is important to discuss this delineation. The kickback of a chain saw is defined by the Association as 1) a sudden unexpected reaction occurring on the upper portion of the guidebar nose causing the guidebar to be driven up and back toward the operator, or 2) a sudden unexpected reaction occurring when the saw chain is pinched by the wood on the upper straight portion of the guidebar, causing the saw to be driven back toward the operator. The first part of the definition for kickback has been termed "classical" and the second part of the definition as "pinch" by the Association; the former was used in the design of the KBM for determining the kickback energy for chain saws. Since the classical kickback almost always has a significant component of

*Hereafter, the Consumer Product Safety Commission and the Chain Saw Manufacturers' Association will generally be referred to as the "Commission" and "Association", respectively; "CPSC" and "CSMA" will be used to delineate the test procedures.

rotational saw motion, the term "rotational" is used in this report to distinguish it from "pinch" kickback, which consists of only linear motion. Due to safety considerations, it was deemed necessary to clamp the chain on the guidebar lower portion for the pinch kickback simulations in the present investigation. Since the magnitude and speed of the kickback reactions are often such that they might introduce hazards to an operator, safety precautions and devices were utilized in all of the simulations which were conducted.

The mechanics of a "classical" kickback event are known only to a limited degree. When the upper portion of the guidebar nose contacts an object, there are forces developed at the saw-wood interface which drive a chain saw upward and back toward the operator. High-speed movies of the tip of a guidebar in contact with a wood specimen indicate that the saw chain elements will rotate and "cam-lock", i.e., rotate about one end of the element chassis, as the chain motion is interrupted. The development of "new technology" chain in the last several years has attempted to mitigate the kickback hazard by the introduction of additional chain elements or the redesign of the chain to reduce the liklihood and severity of such events. However, numerous other factors have been found to influence the kickback severity, as discussed in the following paragraphs.

The magnitude of the kickback is limited by the energy stored in the rotating parts of the saw powerhead plus some additional power generated during the few power strokes of the engine that occur during the interval the saw chain teeth are in contact with the wood. This is the energy available to thrust the saw upward and backward during a rotational mode of kickback [4]. The saw continues to accelerate until the operator exerts forces and moments to the saw at the front and rear handles which prevent continued motion of the saw. It is known that the saw path during kickback occurs in more than one plane. However, the majority of the hand-held kickbacks which have been filmed reveal that the motion does not deviate substantially from a single plane, and the investigations by the Association and the Commission have made the assumption of planar motion. In the cases where specific films have been selected for analyses, one of the criteria in the selection process was to choose tests where the saw appeared to have minimum out-of-plane motion. The latter motion is influenced by the location of the saw center of mass, the design of the saw handles and the operator's grip on the handles, none of which has been systematically investigated.

High-speed cinematography has been used extensively by both the Association and the Commission in their independent experimental investigations of kickbacks for chain saws held by volunteer test subjects. Film speeds in the order of 500 to 600 frames per second have been found to be adequate to define the saw path and to determine the kinematic data required for analyses of the forces and moments which develop at the saw handles. The treatment of noise in the film analysis is discussed in this report and more extensively in References 5 and 6. The direct measurement of accelerations of chain saws during kickback was attempted, but the noise due to the chain saw engines was found to be excessive and broad-band in nature.

Due to the counter-forces and moments exerted by the operator during a kickback, the saw acceleration becomes zero at some time after the initiation of the event but before the saw motion ceases, assuming that he maintains his grip of the saw handles. It is generally assumed that the earliest time in which an operator can begin to react voluntarily to kickback is in the order of 100 or 200 milliseconds after initiation of the event. No systematic investigation has been made of this, so far as is known. The concept of a "relaxed" test operator is

used in the report only in a relative sense, as no measurements were made of an operator's physiological state during any of the simulated kickbacks. One indication of an operator's degree of relaxation was the time required to reach the maximum saw angular motion or, more obviously, whether an agressive saw reached the limits designed for safe testing; i.e., a safety barrier or tether. The University of Maryland Biomechanics Laboratory, in their analyses of selected test films, considered this subject as follows [6]: "It was postulated that in the time period leading up to 200 milliseconds, the muscular action by the operator would not significantly alter the total system (saw plus operator) kickback energy, which should remain approximately constant. Only the operator's arms were considered in the system since little or no motion of other body parts was observed in the film trials analyzed. Initially the operator supported the saw to counteract the force of gravity. It was assumed that during the kickback the arm musculature was passive, and did not contribute to altering the saw motion. In the initial kickback stages such an assumption seems reasonable, given that the kickback force is usually much larger than any force that still might be exerted on the saw during the initial part of the saw upward motion. The saw may, of course, have been held in a "stiff" manner where both the agonistic and antagonistic muscles would have contracted. In such a case, the saw energy would have decreased very quickly as work was done in stretching tense muscles opposing the saw motion. If these assumptions were correct, then the total energy of the saw-operator system should have remained constant until reflex or conscious muscular action of the operator became appreciable. In quite a few of the trials whose films were analyzed, the total energy did remain constant for the time period up to 200 milliseconds after initiation of the kickback. Some trials, however, did show a decrease in total system energy very shortly after kickback initiation." The scope of the Biomechanics Laboratory research did not provide for a complete examination of these results.

II. Simulation of "Rotational" Kickback Motion

A. Background

In 1980, the Commission decided to initiate the in-house development of a mandatory standard to address chain saw kickback. Part of that effort involved relating chain saw energy levels generated in the KBM to the final angle that a saw might travel when held in the hands of a chain saw operator. Reference [2] describes the experimental program developed to determine the relationship between kickback energy and chain saw motion during hand-held kickbacks for selected samples of consumer-type chain saws and volunteer test subjects.

Independently, the Association initiated an experimental study with the objective of developing an analytical model which could relate kickback energy and chain saw motion as part of a voluntary standard addressing chain saw kickback [3]. The subsequent formation of an ANSI Technical Committee to develop a voluntary chain saw safety standard led to the need for evaluating those portions of the Association's analytical model based on their hand-held kickback experimental program. The specific results to be evaluated from the latter program were 1) the magnitude of hand forces and moments which define the operator/saw interaction during a classical, or rotational, type of kickback and 2) the distribution of kickback mechanical energy among rotational, vertical and horizontal components.

In order to evaluate systematically the Association hand-held kickback experimental results, it was necessary to perform a film analysis of selected Association and Commission kickback trials to determine critical test parameters and to compare the results. Since the two kickback experimental programs were

conducted using different test protocols, they are referred to as the Association and Commission simulations in this report. It will be shown that there were advantages and disadvantages with both of the simulations, and that it became desireable to employ both test procedures in the actuation of the brake mechanism for saws equipped with chain brakes as a feature for the mitigation of kickback.

B. CSMA Kickback Test Procedures

The basis for the Association kickback test procedure for simulating hand-held kickback is given in Reference 4. "The magnitude of a kickback is limited by the energy stored in the rotating parts of the saw powerhead plus some additional power generated during the few power strokes of the engine that occur during the interval the saw chain teeth are in contact with the wood. This is the energy available to thrust the saw upward and backward during a rotational mode of kickback.

This transfer of energy depends on the ability of the saw clutch to carry the kickback loads and the ability of the chain-wood interaction to carry the load. Assuming that the available energy and the clutch carrying capacity are relatively high compared to that of the wood-fibre-chain teeth interaction, one can conclude that the key element controlling kickback energy measurements is the chain-wood interaction. This interaction is dependent on the forces that tend to maintain contact between the wood specimen and the saw chain teeth. These forces are, in turn, related to the initial impact velocity, geometry, and the mass and inertia of the moving bodies."

The Association procedure to simulate a kickback, based on the considerations in Reference 4, required that an operator move the test saw into an essentially "fixed" piece of wood. The saw's horizontal motion is arrested by forces developed at the bar tip between the wood and chain teeth, bringing the saw to rest (at least in a horizontal direction). The principal advantage of the CSMA test procedure was that large kickback motion almost always occurs. The disadvantages which have been found relate to the inability to closely control important kickback parameters such as the approach speed, which is determined entirely by the operator, and the tendency to induce large vertical motion for any test saw; the latter is particularly evident if the operator unintentionally imparts an upward momentum to the test saw prior to contact with the wood specimen.

Notwithstanding the disadvantages in the test procedure, it is believed that the Association experimental programs produced some reliable data for 8 out of 10 test subject volunteers*, and it was determined that the CSMA test procedure should be employed when the performance of automatic-chain brake devices are to be evaluated, as discussed later in this report. A comparison of the CSMA and CPSC test procedures will be made after first reviewing highlights of the Commission kickback test program.

C. CPSC Kickback Test Procedures

The basis for the CPSC kickback test procedure for simulating hand-held kickbacks is given in Reference [2]. A kickback test machine (KBM) had been developed and shown in prior investigations to simulate kickback conditions in a

*This judgment was based on a comparison of the horizontal and vertical kickback energies determined by the Association for all the kickback trials which they analyzed.

reproducible manner for determining the energy associated with kickback motion [1]. Kickback is initiated in the KBM by accelerating a carriage, holding a wood specimen, into contact with the moving saw chain on the upper quadrant of the saw guidebar nose.

In the Commission kickback investigations, volunteer test subjects were required to hold an operating test saw in a simulated bucking mode of operation. A pawl and rack mechanism was employed to constrain the carriage's initial rearward motion to transfer the carriage momentum effectively to the saw without unrealistically constraining the test saw. The method selected to accelerate the carriage, control its approach speed, and adjust the specimen contact angle was the same as that used in the KBM. The chain saw initial horizontal position was controlled by using a lightweight shield surrounding the flat portion of the guidebar, which also served to protect the test subject. This procedure simulated a bucking mode of operation in addition to controlling the initial horizontal position of the guidebar to ensure that the wood-saw contact angle was properly maintained.

The principal advantage of the CPSC test procedure was that it enabled a close control of kickback test parameters, which experience with the KBM had shown to be important, such as the impact velocity and contact angle between the wood and tip of the guidebar nose. However, it has been observed that there is a tendency for the smaller size saws to be deflected out-of-plane and to be characterized by relatively large horizontal kickback motion. Subsequent to the experimental program using the CPSC test procedure which was reported in Reference [2], two methods were found for amplifying the saw motion by reducing the tendency for out-of-plane saw motion. The latter were 1) the reintroduction of the saw tip into a previously formed guidebar-nose cut in a specimen (i.e., a "buried" kickback hit) and 2) changing the flat wood specimen surface to an angular surface. The CPSC kickback procedure has been found to produce both repeatable and discriminating kickback test data even without introducing the above "amplification factors." It was necessary, however, to modify the procedure when the performance of manually actuated chain brakes was investigated, as discussed in Section IV.

D. Comparison of Rotational Kickback Simulations

The simulated rotational kickbacks conducted by the Association and Commission were recorded using high speed cinematography, and the test films were subsequently analyzed to determine critical kickback test parameters. The Association kickback tests were conducted, filmed and analyzed by the chain saw industry. The Commission kickback tests were conducted and filmed by NBS, and selected trials were analyzed by the University of Maryland Biomechanics Laboratory, using advanced film analysis techniques [5,6].*

A critical comparison of the Association and Commission kickback simulations was required to enable the Commission to perform their examination of the proposed ANSI analytical model developed by the Association. This evaluation included a comparison of saw path displacements, components of test saw velocities from which to compute the distribution of kickback energy among 3 modes, and the acceleration data required to estimate the forces and moments developed at the saw handles during a kickback. A detailed presentation of several aspects of the Biomechanics Laboratory film analysis procedure is given in the following

*Ten films of the Association kickback trials were also selected to be analyzed by the Biomechanics Laboratory, as will be discussed later.

section since, as will be shown, considerable attention was required in the treatment of noise inherent in the filming of kickback events in order to obtain the necessary kinematic data.

The simulated kickbacks were all recorded on high speed film at the rate of approximately 500 to 600 frames per second. First, the location and orientation of the chain saw in the principal plane of operation, i.e., plane of saw rotation, were determined for every frame analyzed (about 200 frames for most kickback tests). The locations of various points of interest on the saw were calculated as described in the following paragraph. Coordinates of the center of mass of the saw, and saw angle with respect to the horizontal were then filtered and differentiated, as explained in Appendix A, to provide the kinematic data necessary for the calculation of hand forces and moments exerted by the operator and to compute components of kickback energy.

Before the digitizing of each kickback test film was commenced, three to five points on the saw were chosen such that throughout the trial they remained visible, and provided the best contrast. Three frames of the trial before the kickback was initiated were digitized to establish the coordinates of the digitized points in the internal reference frame of the saw. At this time the internal coordinates of other points of interest on the saw (center of gravity, handle coordinates, tip coordinates, etc.) were also determined. The digitizer was directly interfaced to a computer and programmed to use the center of gravity (C.G.) of the saw as the origin of its coordinate system, with its x-axis aligned parallel to the centerline of the saw guidebar. The x,y coordinates output by the digitizer were then defined in terms of the internal reference frame of the saw.

The planar distribution of digitized points determined in terms of the internal reference coordinate system was fitted by a least squares fit procedure to the points on the saw as digitized in each frame, and the transformation for taking the configuration from a reference position to the saw location was calculated. The reference position was the location of the saw at the time of initial wood contact (i.e., the onset of kickback), with the coordinate system origin located at the saw C.G., and the angular displacement measured with respect to the horizontal. In order to determine the true locations of other points of interest on the saw in each frame, the calculated transformation was applied to the internal reference coordinates of the saw. The root mean squared distances of the transformed internal points from the digitized points in each frame were averaged over all frames for each trial. This measure proved valuable in indicating the film digitizing accuracy.

The significance of the above discussion for the analysis of kickback simulations is that 1) the accuracy of conclusions drawn from kinematic and kinetic studies of filmed motion depends largely upon the accuracy of the reference marker displacement, velocity and acceleration measurements; 2) attempts to calculate velocities and accelerations by successive differentiation of filmed displacement data have been plagued by the amplification of the "noise" inherent in such data; and 3) digitizing errors, out-of-plane saw motion, and non-rigid body behavior of a chain saw all contribute to the "noise" present in the measurements [5,6,7].

An indication of the digitizing accuracy was obtained by examining how well the least squares fit procedure was able to align the internal reference point configuration to the digitized points in each frame of film which was analyzed [5]. This measure proved valuable in indicating and subsequently

correcting, if necessary, digitizing errors. In selecting the test films to be analyzed, only those for which the saw path was primarily a single vertical plane were chosen so that errors associated with out-of-plane motion were minimal.

The problems during analysis of films due to non-rigid body behavior of a saw were caused by the presence of flexible, rubber-like, antivibration (AV) mounts within the body of a chain saw. Since these test saws tend to have a greater number of degrees of freedom, the analysis of kickback films for these saws is not considered to be as meaningful as that for "rigid" saws. Accordingly, the data for the saws equipped with AV systems will be noted in the following comparison of the kickback film analysis results.

An indication of the latter difficulties was encountered when estimates of kickback rotary energy by the Association and by the Biomechanics Laboratory were first compared, based only on the motion of the test saw, i.e. neglecting the motion of the operator's arms, The Association estimates for rotary energy for saws equipped with AV mounts were an average of 112 percent larger than the Biomechanics Laboratory values; for saws not equipped with AV mounts, the comparable difference was approximately 25 percent. However, this distinction is not clear when the energy associated with the operator is included in the analysis.

The results of a more complete evaluation of the kickback energy components by the Biomechanics Laboratory, which accounted for the kinetic energy due to the test operator's arm motion, are shown in Tables 1 and 2 [6]. In Table 1, the Biomechanics Laboratory estimates for rotary energy are generally larger than the Association values and tend to agree with the latter more for saws equipped with AV systems. As can be observed in Table 2, the agreement in the determination of total energy, ratio of rotational to total energy, and ratio of horizontal to vertical energy is quite good for five of the kickback trials (Trials 44, 66, 70, 85, and 92). For all ten trials, the average ratio of rotary energy to total energy for the Association and Biomechanics Laboratory analyses were 0.56 and 0.61, respectively. The greater disparity in the proportion of horizontal to vertical kickback energy is probably associated with human errors in digitizing the kickback films and/or treatment of "noise" in the displacement data. It is not apparent, in this more complete evaluation of kickback energy, whether or not the evaluation of the energy distribution is degraded for those saws equipped with AV systems.

When a comparison is made of the kickback test results by analysis of data from simulated kickbacks using both the CSMA and CPSC test procedures, the limitations in such simulations must be considered. The most significant difference which is generally found when such a comparison is made is in the vertical motion of a test saw after it exits the wood specimen. There are several sources for this result which are associated with each of the two simulations.

For the CSMA test procedure, in which a test subject moves a saw into a rigid wood specimen, the operator 1) applied forces to the saw which tend to minimize rearward and out-of-plane saw motion, and 2) sometimes the operator imparted a small vertical momentum to the saw prior to contact with a wood specimen. For the CPSC test procedure, in which a wood specimen is moved into the guidebar tip of a saw held stationary by a test subject, the operator 1) does not apply any forces to the saw which specifically prevent out-of-plane saw motion and 2) sometimes the

Table 1 -- Comparison of Estimated Values of Test Saw Rotary Energy for Ten Kickback Trials

Trial	Anti-Vibration Mounting System	Test Saw Rotary Engergy			
		Association joule	Analysis (in lbf)	Biomech. Lab. joule	Analysis* (in lbf)
22	Yes	7.1	(62.7)	9.8	(86.8)
40	No	7.7	(68.3)	13.4	(118.5)
44	No	18.5	(163.5)	19.1	(168.8)
61	Yes	6.0	(53.3)	4.1	(36.4)
66	No	7.1	(63.1)	7.3	(65.0)
70	Yes	9.8	(86.5)	8.1	(71.5)
85	Yes	9.1	(80.5)	14.9	(132.0)
91	Yes	12.0	(105.9)	5.7	(50.2)
92	No	8.3	(73.3)	13.4	(118.3)
121	Yes	4.8	(43.0)	5.3	(46.7)

*Estimate for saw rotary energy were based on the rotational velocity of the saw and operator's arms as the saw eixted from the wood specimen.

Table 2 -- Comparison pf Energy Analyses by the Chain Saw Manufacturer's Association and Biomechanics Laboratory for 10 Kickback Trials

Trial No.	Total Energy CSMA joule	(in-lbf)	B. Lab joule	(in.lbf)	(Rot. Energy/Tot. Energy) CSMA	B. Lab	(Horiz. Energy/Vert. Energy) CSMA	B.Lab
22	17.9	(158.2)	17.3	(152.9)	0.40	0.57	2.86	1.49
40	13.1	(115.6)	21.3	(188.1)	0.59	0.63	0.28	1.87
44	28.3	(250.5)	26.6	(235.1)	0.65	0.72	0.41	0.44
61	10.0	(88.5)	6.9	(61.4)	0.60	0.59	250.40	8.62
66	10.7	(94.5)	12.5	(110.4)	0.67	0.59	2.17	2.57
70	12.1	(107.4)	11.5	(102.1)	0.80	0.70	0.22	0.31
85	21.9	(194.2)	23.3	(206.6)	0.41	0.64	1.36	1.31
91	14.4	(127.5)	9.4	(83.4)	0.83	0.60	1.67	0.60
92	19.3	(171.2)	20.7	(183.1)	0.43	0.65	1.48	1.58
121	19.8	(175.3)	13.5	(119.9)	0.24	0.39	1.72	2.36

[1] Total system energy is the sum of horizontal, vertical, and rotary kinetic energies for the saw and operator's arms as the test saw exits from the wood specimen.

operator moved the test saw rearward prior to contact with a wood specimen.* A summary of these attributes of the test procedures, in addition to other such characteristics, is given in Table 3.

The principal implication from the above comparison of two kickback simulations is that caution must be exercised in the selection of data from which to draw specific conclusions. As an example, the best agreement in the kickback data using the two simulations was found by plotting the rotation of various test saws about their center of gravity (C.G.) versus the ratio of the test saw total energy to the saw polar moment of inertia, as shown in Figure 1.** The relatively good agreement between the two simulations is attributed to 1) selection of the rotation about the saw C.G. as the best reference for comparing the simulations and 2) selection of data for the CPSC simulation for two test subjects who were considered to be the most "relaxed", i.e., less likely to impose undesired forces on the test saw during the initial portion of a simulated kickback. Attempts were made to compare the CSMA kickback angle versus saw energy and inertia characteristics but were not as successful. It is believed that only the "initial" portion of a kickback simulation during which the saw is permitted by an operator to rotate about its C. G. is suitable for such comparisons. (Since control of a test saw was maintained by a test subject during either the Association or Commission kickback simulations, at some time during the kickback, the operator generally applies forces and moments to the saw to prevent its further rotation about the saw C. G.).

E. Interrelationships Among Chain Saw Test Parameters

The use of kickback energy alone as a criterion for a chain saw safety standard is known to be deficient since it does not account for important saw kickback parameters. Two such parameters which have been identified are the saw polar moment of inertia (PMI), which is a measure of resistance to saw kickback rotation, and the spacing between the saw front and rear handles, which influences the counter-moment which an operator can exert to resist chain saw rotational kickback. It is likely that these two parameters are themselves interrelated, but their relationship could only be established relative to other kickback parameters. The handle spacing will be discussed first.

A specific objective in this investigation was to examine whether handle spacing, either singularly or in combination with a test saw PMI, would better define the relationship between kickback energy and the derived angle of saw rotation. In an earlier study, the influence of handle spacing was investigated for a chain saw equipped with two throttle trigger locations on the rear handle [2]. Unfortunately, the variability in measured saw motion during hand-held kickback tests was such that a clear understanding of the effect of handle spacing could not be obtained. In the present study, a number of test saws representing a wider range of handle spacing were tested and the influence of this parameter on the kickback motion could be more clearly ascertained.

*This was observed during 5 of the 630 Commission simulated kickback trials.

**Kickback data for two Association test saws equipped with AV systems were omitted, based on earlier discussion of the problems associated with analyses for such saws. The values determined for the saw angle represent the first peak in the rotation of a saw about its center of gravity.

Table 3 -- Comparison of CSMA and CPSC Kickback Test Procedures

Attribute	CSMA Procedure	CPSC Procedure
Saw Constraints	Supported only by Operator	Guidebar supported on wood block, rear supported by operator
Saw Initial Motion	Moved into wood by operator	None (wood moved into inert saw)
Factors Affecting Repeatability	1) Initial upward motion of saw prior to wood contact.* 2) No control of initial saw velocity by operator. 3) Operator state of tension/relaxation.	1) Initial rearwood motion of saw prior to wood contact.* 2) Out-of-plane saw motion (particularly for smaller saws). 3) Operator state of tension/relaxation.
Factors Known to Amplify Saw Motion	1) Initial vertical momentum of saw	1) Buried hits** 2) Shaping of wood contact surface to minimize out-of-plane saw motion.**

* This inadvertant operator action although usually negligible can have a large effect on saw motion.

** These factors were determined during auxilliary kickback tests that were not part of the normal CPSC procedure.

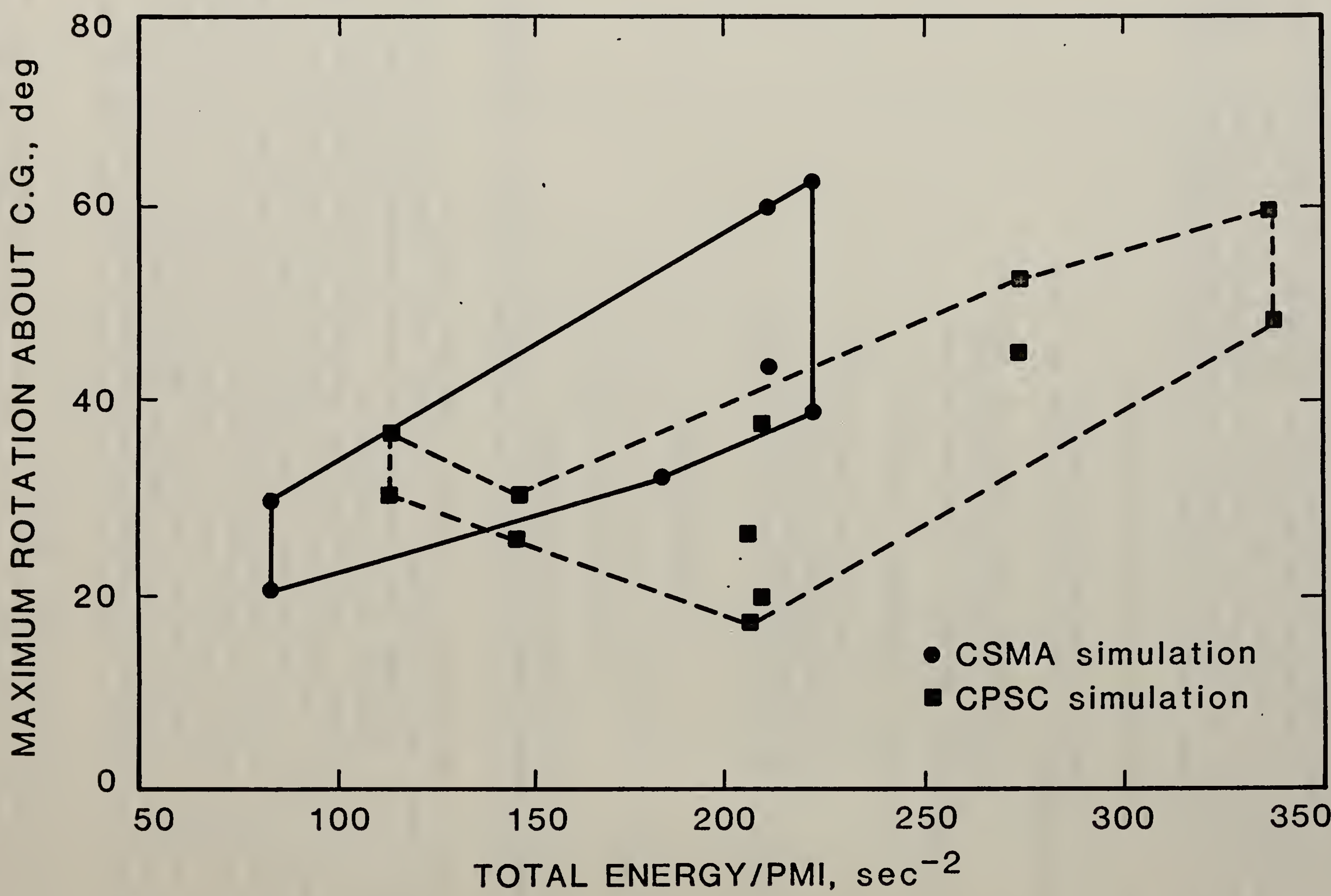
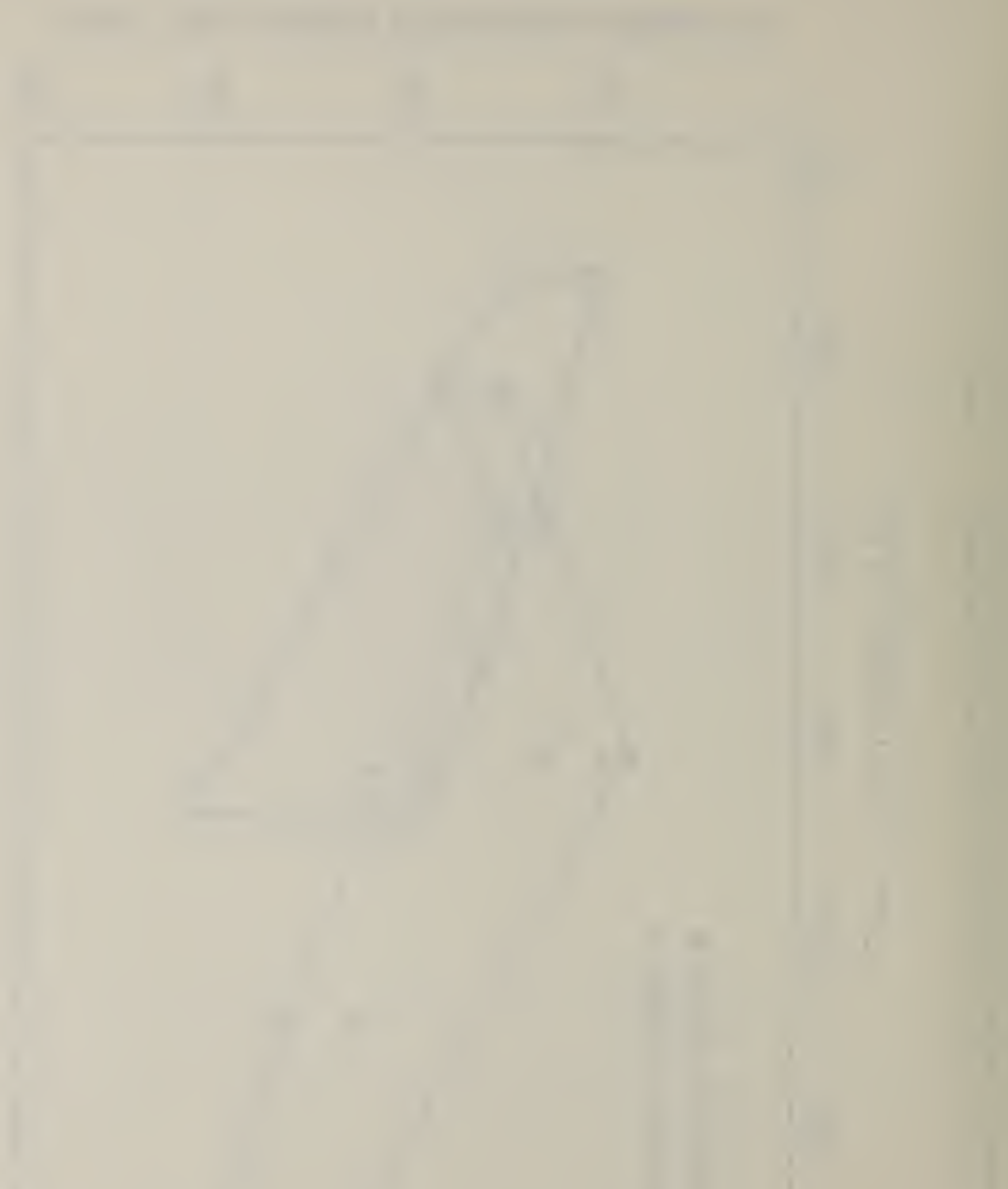


Figure 1 -- Comparison of Saw Total Energy/Polar Moment of Inertia with Rotation About Saw Center of Gravity During Kickback.



Initially, an attempt was made to consider the handle spacing as an independent parameter and to establish its relationship to the saw kickback motion. A chain saw manufacturer, who assumed some "average" operator holding the saw, suggested that as the handle spacing for a given saw increased in length, the saw kickback angle decreased in an approximately linear manner. No experimental data were provided to substantiate this theory.

In the present study, an indication of the influence of handle spacing, as determined from analysis of kickback films for saws held by various test operators, was initially found by comparing handle spacing with the ratio of a saw rotary energy to its PMI as the saw exits a wood specimen. This relationship had several disadvantages; namely, there was significant scatter in the values for saw rotary energy, which were determined by analysis of films for simulated kickbacks, and relatively few trials had been selected for the film analyses. Furthermore, the kickback angle of the saw was the variable of primary interest to the Commission. Thus, computed angles of saw rotation were used to supplement data from the film analyses. These angles were determined by the Commission, using an analytical model developed by the Association. The latter model required assumption of an "average" chain saw operator whose characteristics were inferred by pooling data from 10 volunteer test subjects each of whom held various selected chain saws during kickback trials whose films were analyzed.

The following empirically derived equation was found to provide the clearest relationship between handle spacing and the kickback angle for a simulated kickback of a chain saw held by an operator:

$$\text{CSMADAR} = C_1 \ln \left(C_2 \frac{\text{Corrected Rotary Energy}}{\text{Handle Spacing}} \right)$$

where

CSMADAR = Association definition of the derived saw rotational angle, relative to a fixed reference at the saw rear throttle trigger location [2].

ln = natural logarithm to the base e.

Corrected Rotary Energy* = difference between a test saw rotary and linear energy determined in the Kickback Test Machine.

Handle Spacing = linear distance between the front and rear handles of a test saw.

C_1, C_2 = empirically determined constants.

A plot of this relationship for a sample of chain saws equipped with either original equipment or with new technology chain is shown in Figure 2. Values from the theoretical analysis by a chain saw manufacturer for a small range of handle spacing is also shown in the figure. For the sample of saws investigated, the approximate values for the constants C_1, and C_2 were 30 and 0.5 to 0.6, respectively. Although the empirical relationship found is indicative of the effect of handle spacing on the chain saw kickback motion, additional test data may indicate the need for improved values for the

*Also referred to as "Computer Rotary Energy" in Reference 3.

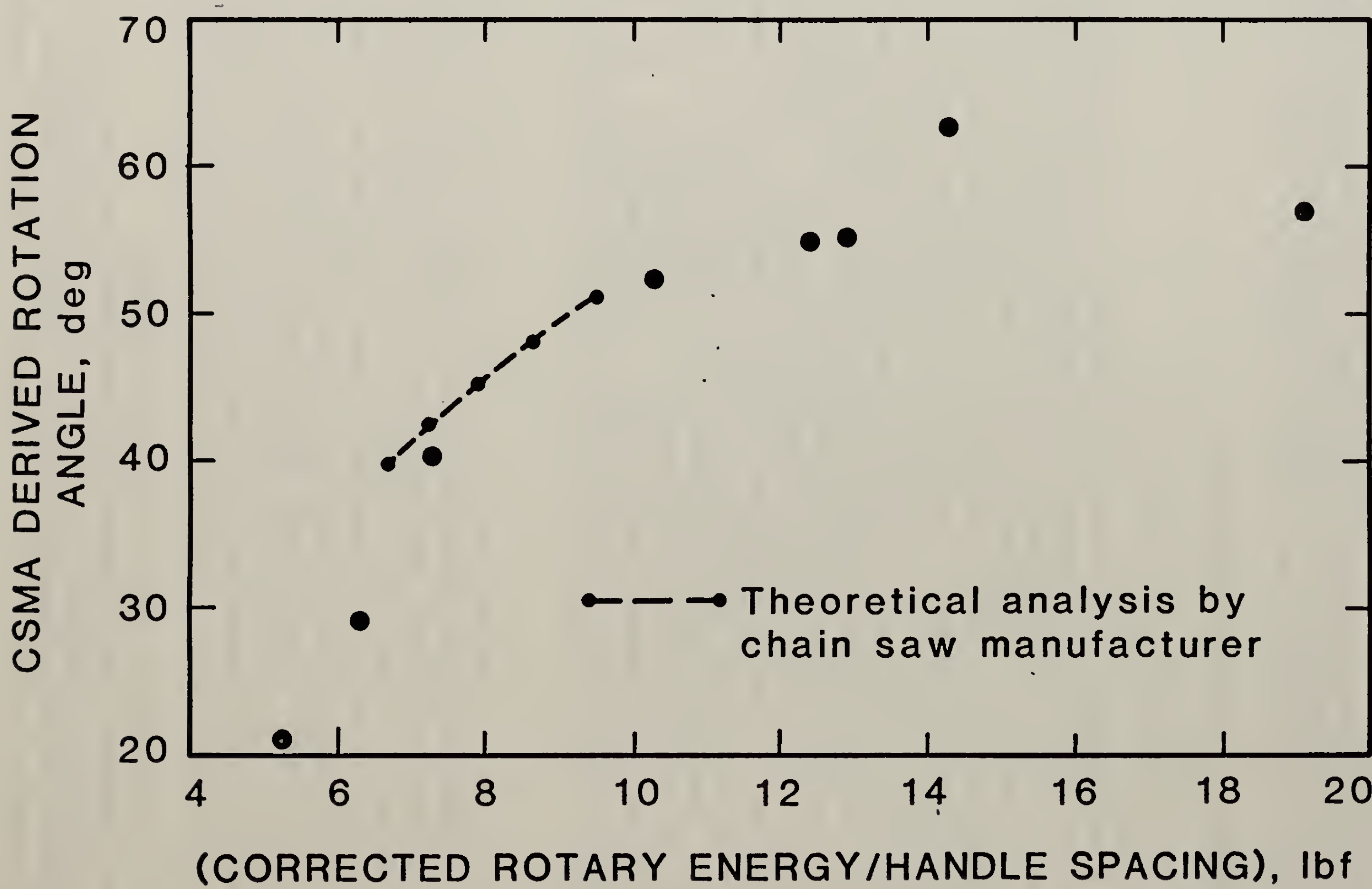
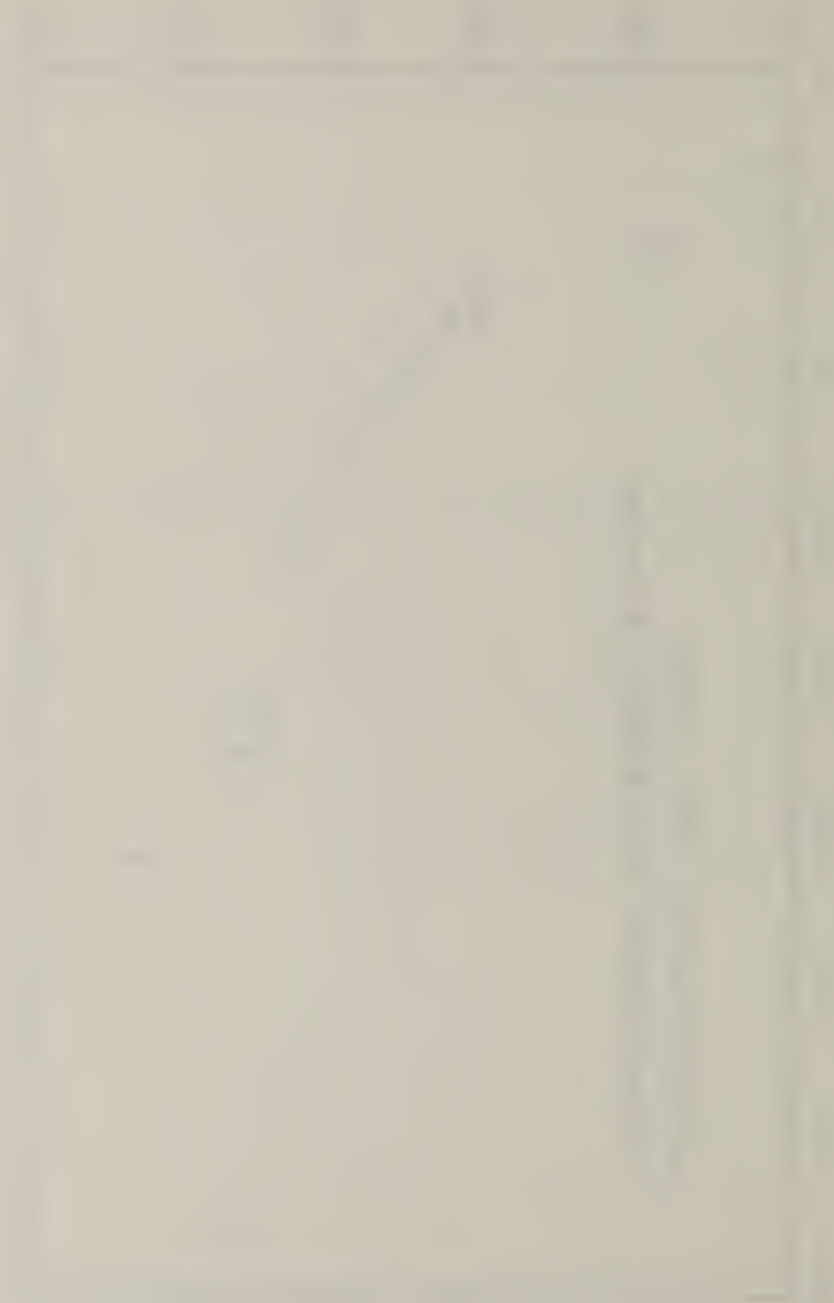


Figure 2 -- Comparison of Handle Spacing Parameter with Saw Derived Angle of Rotation.



coefficients, or may suggest that a range of coefficients is required, depending on the saw chain or other such variables.

Continuing attempts have been made to establish a relationship between the kickback energy, saw polar moment of inertia (PMI) and the angle of saw motion from simulated kickbacks. Generally, there is considerable scatter in the test data whenever such attempts have been made for a variety of test saws. One source of this scatter may be the handle spacing.

Another likely reason that it has proved difficult to correlate the saw PMI with the angle of saw kickback motion directly is due to the complexity in the saw path over the entire simulated kickback trial. For either the CSMA or CPSC kickback trials, observation of high-speed films has indicated the tendency for a test saw to rotate initially about its center of gravity (C.G.). It is during this period that the saw PMI is expected to have its clearest relation to the saw rotational motion. Even when a longer period of kickback motion is considered, it has been found that the ratio of saw kickback energy to PMI is clearer when compared to the rotation of the saw about its C.G. as indicated previously in Figure 1, rather than to the CSMA or CPSC derived angles of rotation.

During initial attempts to correlate saw PMI with other parameters, it was established that some value of the saw energy divided by the PMI was related to a test saw kickback rotation [2]. Various measures of a test saw's kickback energy potential have been employed in investigations to establish this relationship. Among the latter have been 1) the total energy, rotary energy or corrected (computer) rotary energy, all based on measurements in the Kickback Machine (KBM), and 2) the total system or total kinetic energy, based on analysis of high-speed test films of simulated kickbacks. Although there is scatter in all of the kickback energy measurements, there is a greater degree of confidence in the KBM values, and the corrected rotary energy appears to be the best energy value with which to relate the saw PMI and kickback angular motion based on available test data. An example of the relationship among these parameters is shown in Figure 3. All of the data plotted were for kickback trials of gasoline powered saws operated at full speed and using the CPSC kickback test procedure. Additional kickback tests conducted for electric powered saws, at lower engine speeds or for saws with special cutting attachments were found to show markedly different relationships among the saw parameters investigated and thus were not included in this presentation.

III. Simulation of "Linear" Kickback Motion

A. Development of Pinch Test Equipment

The objective in developing a test fixture to simulate a linear, or pinch type of "kick" motion was momentarily to clamp the chain on the lower flat portion of a guidebar to interrupt the motion of the chain. The lower run of the chain was clamped, causing the test saw to be pulled away from the test operator. In this simulation, the guidebar itself was lightly clamped, if at all.

Since medium-density fiberboard material had been shown to produce consistent test data in the Kickback Test Machine (KBM), it was chosen as the "wood" specimen material for simulating the pinch hazard. Initial results confirmed that the end grain produced larger saw motion, as was expected, based on the use of fiberboard material in the KBM. A low friction carriage assembly, the lower portion of which was identical to that used during development of a test fixture for hand-held rotational kickback experiments, was used to clamp against a set of rigid wood specimens [2]. The upper portion of the carriage assembly, shown

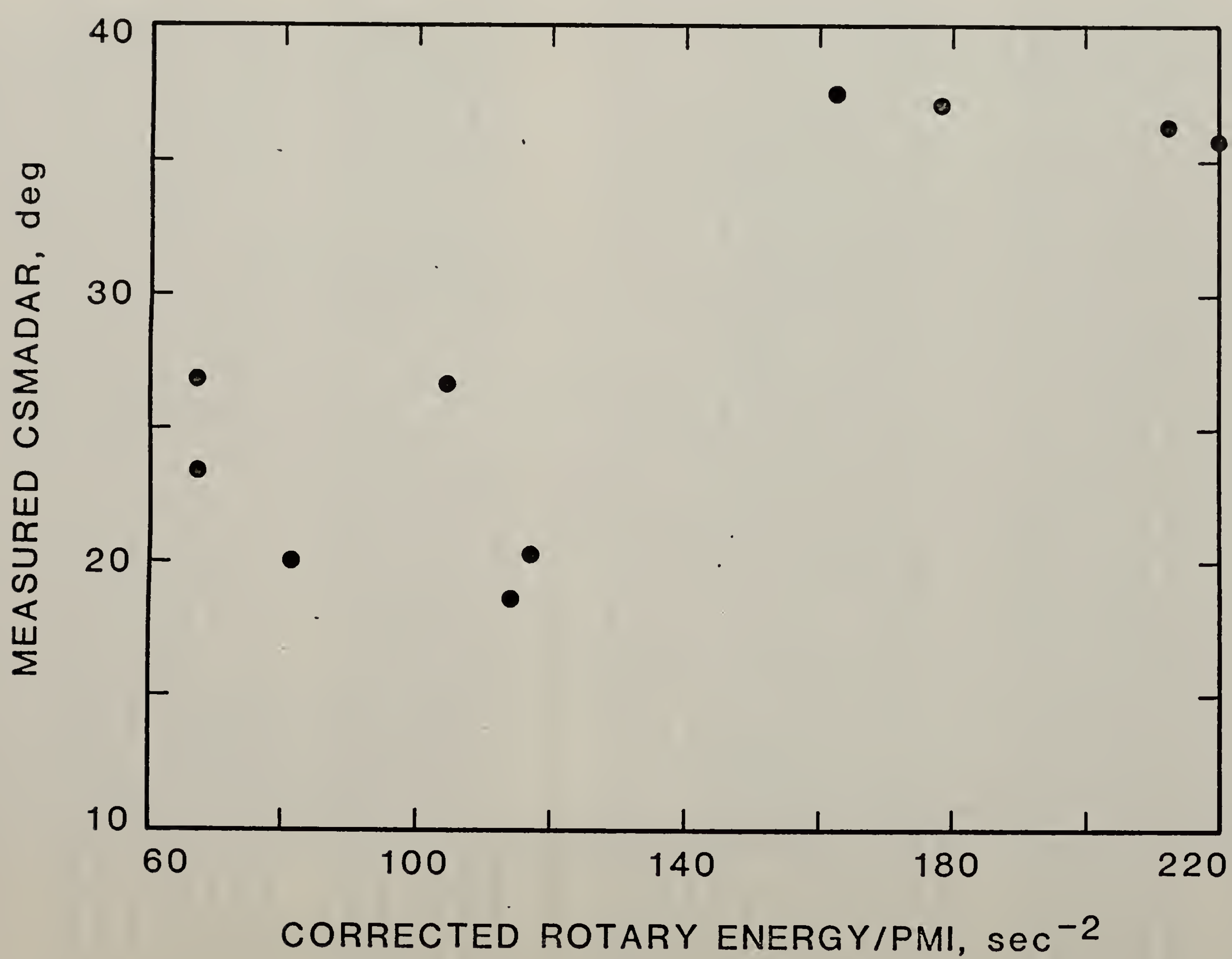


Figure 3 -- Comparison of Kickback Machine Energy/Polar Moment of Inertia with Measured Angle of Saw Rotation.

in Figure 4a, was obtained from a human factors kickback apparatus, and was capable of clamping from one to four 1.5 inch wide wood specimens. The test saw pinch velocity, i.e., the linear saw velocity caused by momentarily pinching the chain on the lower portion of guidebar, was found to increase as the width of clamped wood specimens was increased to the maximum of 6 inches. Thus, all of the remaining tests were conducted using the 6 inch clamping width.

In order to accelerate the movable wood specimens against the rigid wood, a pneumatically driven piston having a cross section area of 1 square inch was connected to the rear of the low-friction carriage as shown in Figure 4b. The pneumatic supply used was a tank of compressed nitrogen, whose pressure was regulated up to approximately 60 psi.* Thus, the maximum clamping force delivered to the movable carriage was 60 pounds. It was assumed that the saw's pinch velocity would be the same as though the chain on the upper portion of the guidebar were clamped, but this was not confirmed due to the safety considerations noted earlier.

Initially, the duration of the clamping force was adjusted by manual operation of a switch connected to the piston-solenoid assembly. However, the manual procedure was later automated by employing a photographic timer having a minimum setting of 0.1 second in order to control the clamping force duration, since the duration of clamping force was judged to be a significant factor in the simulation of pinch-induced saw motion. Photographs of the general test arrangement for simulating linear saw motion are given in Figures 4c and 4d.

B. Measurement of Test Saw Motion

Before meaningful measurements could be made of the chain saw linear motion during a pinch hazard simulation, it was necessary to determine a value for the duration of the clamping force. An electric saw equipped with a Top Sharp (TS type) chain was held as shown in Figure 4c. The lower portion of the saw guidebar was clamped and its forward linear velocity was measured with a photocell indicator. Four tests were conducted using fixture actuation times of 0.1, 0.2, 0.3, and 0.4 second. A plot of the test saw average pinch velocity versus the actuation time is shown in Figure 5, where it is shown that an actuation time of 0.2 sec. produced the largest pinch velocities. The "fixture actuation time" is used to indicate the time set on the adjustable timer; the actual duration of the clamping force was somewhat shorter since the moveable wood specimen had to travel approximately 1 inch before making contact with the saw guidebar.

The test procedure involved arrangement of the wood specimens to simulate the flat cut surface of a 6 inch diameter log during a saw bucking operation and positioning of the test saw relative to the photocell velocity indicator, so that the saw was always set at the same initial position relative to the photocell light beam. Instead of holding the saw unsupported as shown in Figures 4c and 4d, it was placed on an adjustable table to provide better repeatability and to enable the saw to be clamped at a new wood surface for each test.

A brief experimental program was conducted to determine the importance of chain saw parameters on the pinch velocities. The influence of chain design is indicated by tests conducted on a 1.75HP electric saw equipped with seven different chains. The results, shown in Table 4, indicate that five different

* Larger pressures would have required stronger hose connectors and were not required to simulate large saw linear motion.

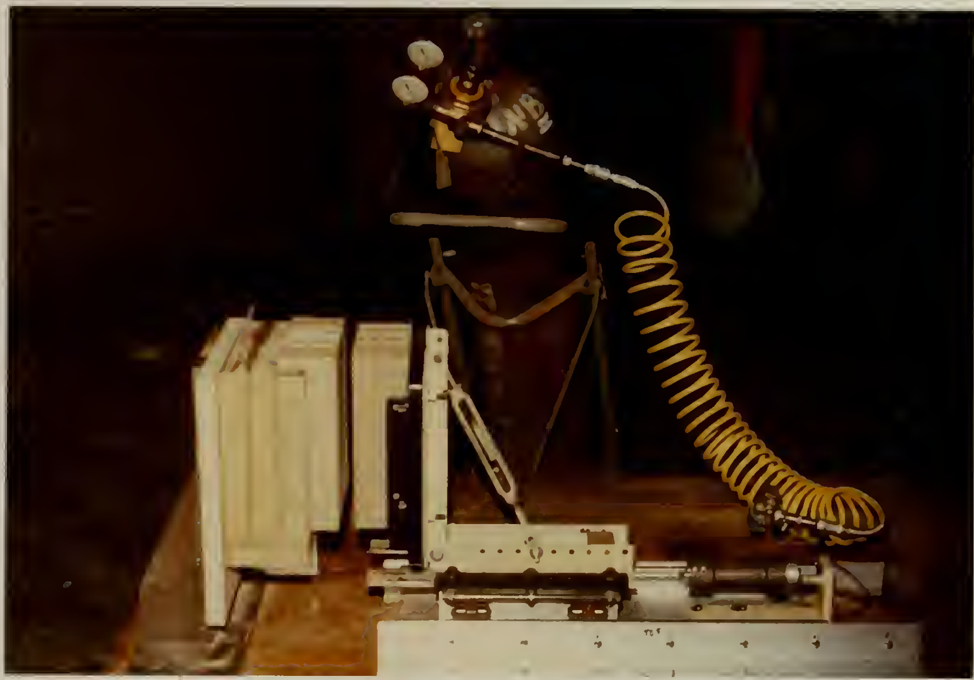


Figure 4a -- Pinch Fixture with
Pneumatic Supply

Figure 4b -- Connection of Pneumatic
Piston to Carriage

Figure 4c -- Test Arrangement to Simulate
Pinch Hazard

Figure 4d -- Close Up View of Pinch
Simulation

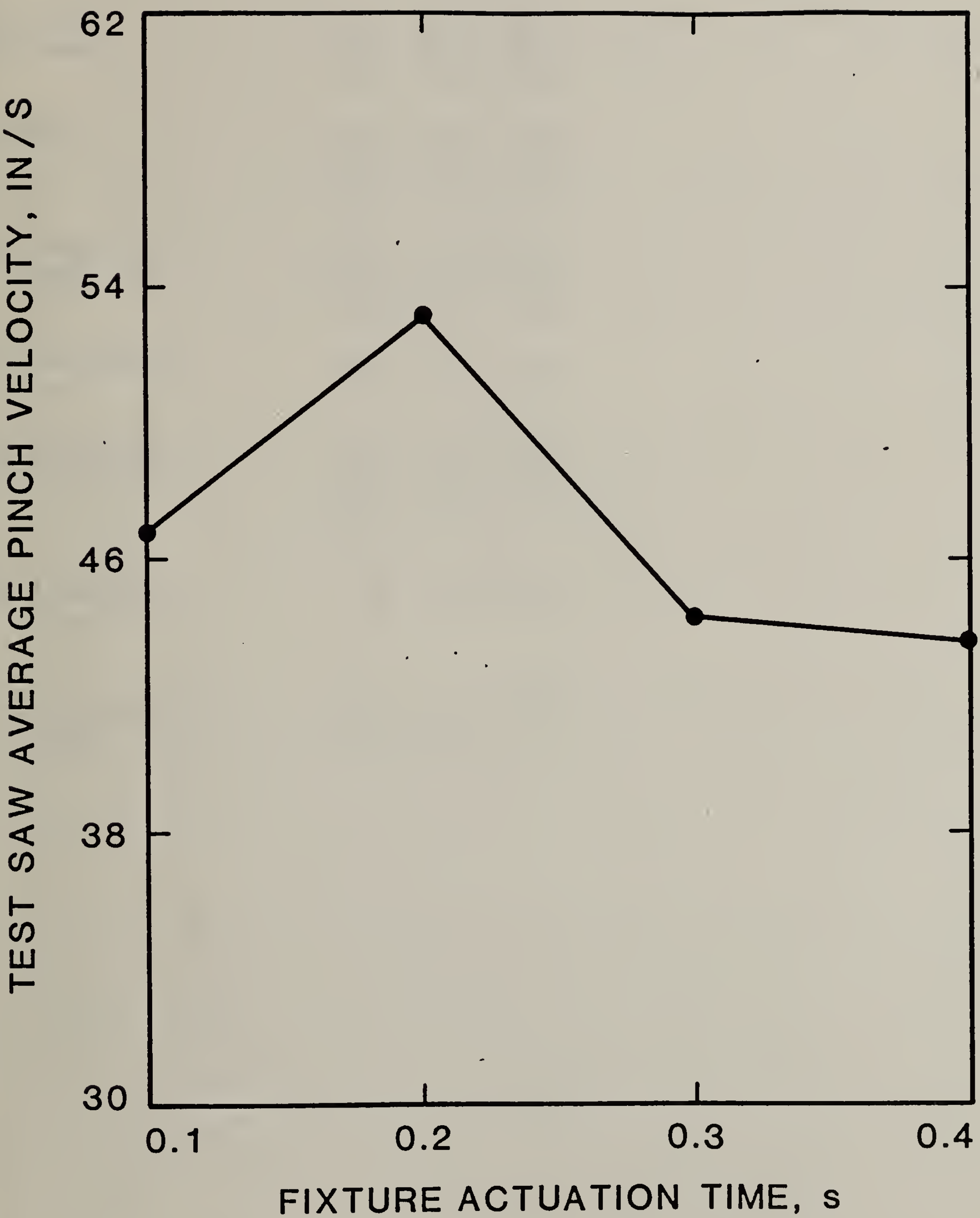


Figure 5 -- Variation of Saw Linear Velocity
with Test Fixture Actuation Time
During Pinch Hazard Simulation.

Table 4 -- Pinch Kickback Velocities for 1.75 HP Electric Saw Equipped with Various Chanins

Chain Type	(Pinch Velocity Successive tests) (in/s)	Average Pinch Velocity (in/s)
Original Equipment	61.4, 53.6, 46.8 52.8, 42.2, 36.0 31.9, 34.5, 29.0.	43.1
Standard	30.9, 32.9, 21.6 24.6, 16.6, 15.9, 12.9, 11.4, 10.7.	19.7
New Technology Type A	46.8, 37.2, 28.7, 27.3, 32.5, 25.0, 22.2, 20.8, 16.0.	28.5
New Technology Type C	35.9, 17.3, 22.2, 17.5, 13.7.	21.1
New Technology Type E	29.1, 28.6, 26.0, 26.4, 21.9, 22.2, 12.9, 13.6, 11.4, 13.0.	20.5
New Technology Type F	11.2, 8.6, 13.7, 7.3.	10.2
New Technology Type H	26.2, 22.7, 24.8, 21.7, 19.8.	23.0

types of "new technology" chain and one standard chain produced substantially lower pinch velocities than the saw's original equipment (TS type) chain.* Pinch kick tests for three electric and for ten gasoline powered chain saws, which are summarized in Tables 5 and 6, indicate the possible importance of saw mass on the measured pinch velocities. It was not possible, in general, to isolate the saw mass from other potentially important parameters, such as chain design and engine speed, during the limited program which was conducted. However, the effect of engine speed on the pinch velocities was investigated for one gasoline powered saw, and the data are shown in Table 7.

IV. Simulation of Kickbacks for Chain Saws Equipped With Chain Brake Systems

A. Experimental Procedures for Actuation of Automatic Brakes

Based upon extensive laboratory experience with both the CSMA and CPSC procedures for simulation of rotational kickback motion, an attempt was made to actuate the chain brake devices for saws which, upon activation, halt a saw's moving chain. Such an examination was judged by the Commission to be required to evaluate the technical adequacy of the treatment of the chain brake in the proposed voluntary (ANSI) standard for chain saws. Before discussing the brake actuation experiments and test results, it is important to define several terms pertaining to chain brake systems.

A manual chain brake depends primarily upon actual inadvertent hand contact and involuntary application of a subsequent contact force for its activation. An automatic chain brake activates either as a result of inadvertent hand contact or when the saw itself detects kickback-related motion (i.e. when a sufficient level of acceleration is imparted to the brake mechanism). A hand guard is a shield located directly in front of the front handle on a chain saw. Its function is to protect the left hand from contact with the saw chain, should the left hand slip off the front handle. The chain brake lever for a saw with a manual or automatic brake also serves as a hand guard.

From earlier experience with the actuation of automatic chain brakes when conducting tests in the KBM [1], and from discussions with the chain saw industry, it was known that some threshold value of acceleration was required to actuate an automatic brake. Thus, the CSMA kickback test procedure was used to generate the levels of kickback acceleration which were judged to be sufficient for brake actuation with, however, closer control of the test parameters being required.

The procedure for adjusting the actuating mechanism for automatic brakes is considered by the chain saw industry as proprietary information. It has been indicated by a few manufacturers that the threshold acceleration required to actuate a chain brake should be in the order of 50 "g's".** Thus several exploratory kickback tests were conducted in which a chain saw equipped with an automatic brake was manually thrust into a rigid wood specimen to achieve the necessary acceleration. Once the minimum effort to actuate the brake was achieved, the test was repeated as nearly as possible. A low wood contact angle, in the order of 5 to 15 deg, was found to result in sufficient kickback motion; only two experienced operators participated in these tests due to the intensity of the kickbacks.

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*"New Technology" chain is generally characterized by such features as "low profile", "guard link" or other features to reduce cam-locking of the chain cutters.

**This measure of linear acceleration is meaningless in the context of the rotational kickback simulations for the actuation of chain brakes.

Table 5 -- Pinch Kickback Velocities for Electric Powered Chain Saws Equipped with Various Chains

Test Saw	Weight (lb)	Type Chain	Pinch Velocity (successive Tests) (in/s)	Average Pinch Velocity (in/s)
E1	7.1	Top Sharp	61.4	
			53.6	
			46.8	
			52.8	53.6
E2	9.1	Low Profile	23.7	
			21.5	
			19.7	
			17.5	
			17.3	
			20.1	20.7
E3	9.6	Standard	12.8	
			18.2	
			12.8	14.6

Table 6 -- Pinch Kickback Velocities for Various Size Gasoline Powered Chain Saws

Test Saw	Weight (lb)	Type Chain	Pinch Velocity (successive tests) (in/s)	Average Pinch Velocity (in/s)
GP1	8.7	Standard	54.6, 76.3, 81.8, 61.3, 71.9, 74.5, 59.9	68.6
GP2	9.3	Low Profile	17.8*, 27.8	N/A
GP3	9.66	Low Profile	26.9	N/A
GP4	10.58	Low Profile	23.6, 15.3, 18.8, 17.7, 16.2, 16.5, 18.4, 19.2	18.2
GP5	11.58	Low Profile	12.4, 15.7, 16.0, 13.4	14.4
GP6	12.16	Standard	3.7, 8.9, 9.1, 3.6, 2.7, 11.5	6.6
GP7	12.94	Low Profile	9.9, 12.2, 7.1, 4.6, 4.0	7.6
GP8	13.2	Standard	15.2, 14.7 11.3	13.7
GP9	16.28	Standard	16.5, 17.4, 7.3, 13.8	13.8
GP10	16.5	Standard	25.2, 21.9, 17.3, 27.6, 18.9	22.2

*Engine speed for Saw GP2 was 12,500 rpm for the first test and 9,500 rpm for the second test. All other saws were tested at full throttle speed.

Table 7 -- Effect of Engine Speed on Pinch Velocities for Test Saw GP1

Engine Speed (rpm)	Pinch Velocity (successive tests) (in/s)	Average Pinch Velocity (in/s)
10,000	37.8 34.9 33.9	35.5
8,000	24.9 22.4	23.6
6,000	11.4 9.4	10.4

Table 8 indicates the frequency of brake actuation for two saws equipped with an automatic brake. Tests conducted for a third saw so equipped are omitted, since it was judged that the brake actuation mechanism was improperly set.

B. Experimental Procedure for Actuation of Manual Brakes

In the development of a procedure for actuation of a chain saw with a manual chain brake, one is confronted with the need to simulate contact between an operator's left hand and the saw brake lever (hand guard). The method for accomplishing this is suggested in a Commission correspondence on chain brakes as follows [8]:

"Since a hand rotation into the brake lever, or a forward dislodgement of the hand into the brake lever, is required to trip a manual brake, then, unless such motion occurs, there is no opportunity for the brake to be activated. A relaxed and loose left hand grip, as a professional or very experienced user might have, offers a better possibility that the hand will move into and trip the brake."

In order to simulate the actuation of a saw with a manual brake system, the CPSC kickback test procedure previously discussed was used with several modifications. First, the test operator stood on a platform whose height was adjusted so the operator's left hand could be located closer to the brake lever before the kickback was initiated. Since it has been found that the kickback motion was enhanced by the reintroduction of the guidebar nose into a previous cut, two or three kickbacks were conducted using the same wood specimen. Finally, the CPSC procedure was modified such that the left hand grip was relaxed, while still maintaining complete control of the saw's front handle in accordance with Reference 8, in order to increase the probability for hand contact with the brake lever.

The data given in Table 8 represent the frequency of brake actuation for three saws equipped with manual brakes. Two of the saws were held by two different operators. In Table 9, a summary is given of the approximate saw angles of rotation about the center of gravity and time intervals from kickback initiation when the brake lever first moved and when the chain motion stopped during one kickback test for Saw A and for five tests for Saw B.

V. Discussion

In summarizing the principal results which have been presented in this report, it is convenient to discuss the kickback simulations in the order of increasing complexity. Thus, the simulation of linear kickback, involving reproduction of a single translational motion, will be discussed first. Then the simulation of rotational kickback, involving two test procedures for reproducing primarily saw rotation in a plane but including translational motion, will be discussed. Finally, the simulation of kickbacks for chain saws equipped with chain brakes, which requires modification of the basic rotational kickback simulations, will be reviewed.

A. Linear Kickback

Based on the experimental program to simulate linear kickback or "pinch", the following results were achieved:

1) A test fixture and procedure were developed for reproducing a momentary interruption of saw chain motion which simulates a translational mode of kickback action. The latter was produced by briefly applying a clamping force; i.e., by "pinching" the chain on the flat portion of a chain saw guidebar.

Table 8 -- Frequency of Brake Actuation for Saws Equipped with Chain Brakes During Hand-Held Kickback Tests

Chain Saw	Chain Saw Characteristics Engine Capacity	Brake	A/V Systems	Test Operator	No. of Actuations	No. of Tests
A*	2.7 in^3	Automatic	Yes	1	3	3
B	2.1	Manual	Yes	2	8	11
C	2.3	Manual	No	1	0	4
				2	4	13
D	3.5	Manual	No	1	5	14
				2	0	5
E	2.4	Automatic	Yes	1	8	18

*For Saws A and E, kickback was initiated using modified CSMA procedures; for all other saws the CPSC test procedure was used but the guidebar top engaged into previous cuts of the wood specimens, i.e., to simulate "buried kickback."

Table 9 -- Chain Saw Kickback Angles and Time Intervals during Brake Actuation for Test Saws A and B

Chain Saw	Test Operator	At Brake Actuation* Saw Angle (deg)	Time from Contact (s)	As Chain Motion Stopped Saw Angle (deg)	Time from Contact (s)
A	1	5	0.020	23	0.140
B**	2	11	0.034	20	0.090
		12	0.050	21	0.100
		13	0.034	21	0.110
		13	0.040	22	0.104
		14	0.040	24	0.122

* Brake "actuation" was assumed to begin when the brake lever was first observed to move away from the saw front handle.

** For tests on Saw B, the saw angles correspond to the angle of the guidebar safety shield with respect to its initial horizontal position.

2) The pinch test equipment included a method for varying both the magnitude and the duration of the pinch clamping force. Initial values for the clamping force and its duration selected for reproducing measureable and repeatable pinch kicks were 60 pounds and 0.2 second, respectively.

3) Test data for ten gasoline and for three electric powered chain saws indicated that the type of chain design and the saw mass are important parameters which can influence the values of test saw pinch velocity. The test saw engine speed can also affect the pinch velocity, as suggested by the more limited investigation of this parameter.

B. Rotational Kickback

The relatively comprehensive experimental programs for the simulation of rotational kickback conducted by the Association and Commission have revealed several principal sources of kickback variability; including 1) variability associated with different test subjects who operated the chain saws, 2) variability among the test saws and their cutting attachments, and 3) variability in the two methods of kickback simulation and the subsequent analysis of the high-speed test films to obtain the critical kinematic data. Notwithstanding these considerations, the following principal results are noted:

1) An extensive analysis of high-speed films for ten Association kickback trials by the University of Maryland Biomechanics Laboratory indicated close agreement with the Association evaluation of the total kinetic energy and the distribution of rotational, horizontal and vertical kinetic energies for five of the trials. Sources of variability in film analysis are thoroughly discussed in the references which document the Biomechanics Laboratory research. The latter included the modeling of a system which accounted for the kickback energies attributed to motion of the test operator's arms in addition to the motion of the saw.

2) Different values of saw rotational motion have generally been obtained for the Association and Commission kickback simulations. Several sources of this variability were identified and discussed in this report, including methods found to amplify the saw motion for either simulation. Relatively close agreement was obtained between the two kickback simulations if a) the test saw rotation about its center of gravity is used as a basis for comparison instead of a derived angle of motion, and b) only test data for two "relaxed" operators during the Commission kickback simulations are considered in the comparison.

3) An empirical relationship was found which relates the handle spacing of a test saw and the difference between the saw rotary and linear energies, measured in the KBM, to the angle of saw rotation. The equation relating these parameters contains two constants, for which values are suggested based on available test data. Additional data may indicate the need for improved values for the coefficients depending on chain design or other saw variables. The empirical relation also indicates close agreement with an analytical evaluation of handle spacing over a limited range by a chain saw manufacturer.

4) Several examples were shown which indicate that the ratio of kickback energy to the saw polar momement of inertia (PMI) is closely related to measured values for test saw rotation. There is, however, considerable variability in such data, and no relationship was found for the energy in combination with PMI which could encompass a wide variety of chain saws and saw cutting attachments. It is known from examination of the Association and Commission kickback simulations that a test operator can significantly influence the distribution of the kickback energies, which is one of several possible sources of variability in the saw motion and energy data.

C. Kickback Simulation for Saws Equipped with Chain Brakes

The simulation of kickbacks for the purpose of actuating manual or automatic chain brakes required modifications to the basic test procedures for reproducing rotational kickbacks. It was determined from an earlier experimental program that, in general, a test subject's left hand did not rotate about the saw front handle in a manner required to activate a manual chain brake [5]. In the case of saws equipped with an automatic chain brake, where the brake actuation does not depend on the operator's hand movement, it is necessary to simulate a kickback such that inertia forces are developed which are sufficient to actuate the brake. Based on the limited investigation which was conducted to simulate kickbacks for test saws equipped with chain brake systems, the following observations are made:

1) In order to reproduce a kickback which enhanced the probability for activation of a manual chain brake, it was necessary that the test operator initial position be adjusted to bring the left hand in closer proximity to the brake lever, and that the kickback motion achieved using the CPSC test procedure be amplified by reintroducing the saw guidebar nose into a previous cut of a wood specimen.

2) In order to consistently reproduce a kickback to actuate an automatic brake, it was found necessary to employ the CSMA kickback procedure to insure that the necessary brake actuation forces developed. Only very experienced test operators should conduct such a simulation.

3) Two test operators participated in the experiments to reproduce kickbacks for saws equipped with manual chain brakes. The success in brake activation for this limited study appeared to depend both on the test operator and on the saw design. In this regard, it is noted that the distance between an operator's left hand and the lever for a chain brake depends both on the saw handle/brake lever configuration and the size of the operator's hand.

VI. Acknowledgements

The assistance of Mr. H. Lucas and Ms. V. Brown of the Consumer Product Safety Commission in the kickback simulation experiments is gratefully acknowledged. Ms. L. Santelli assisted in the computation of the derived angles of saw rotation used in the investigation of interrelationships among kickback parameters. Mr. J. Huckeba recorded the kickback trials on high-speed film and assisted in the design of the linear kickback test apparatus. Dr. A. Dainis of the University of Maryland Biomechanics Laboratory provided valuable information in the filming of the Commission kickback simulations and in the evaluation of the Association experimental data.

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Appendix A -- Limitations in the Film Analyses

In Reference [5] of this report, a discussion is given of the limitations in the Biomechanics Laboratory film analyses used to determine kinematic data for computing the mechanical energies and other important kickback variables. A portion of this discussion is included in this appendix with some additional observations.

In interpreting the data obtained from high-speed films of the Association and Commission kickback simulations, certain limitations of the analysis should be noted. Quite frequently, the test saw underwent motion out of the vertical plane, as well as twisting about its longitudinal axis. Since these motions were not measured, they represent sources of errors in the results. Twisting action which provides an apparent motion of the test saw center of gravity in the vertical plane may be expected to cause significant errors (in this regard it should be remarked that only those films for which the saw out-of-plane motion was minimum were selected for analysis).

The vibration of the saw, quality of the film records, and digitizing errors all contributed to the necessity of smoothing the displacement data before differentiation was carried out. The filtering process ideally attenuates the higher frequency components of the motion, leaving the data that is of interest unaltered. However, the quality of the films, the vibrations of the saw, and the large accelerations experienced during the saw-wood contact phase made it difficult to determine with confidence a filter cut-off fequency which left all of the data of interest unaltered. Since there does not exist a measurement and analysis technique to test appropriate choices of smoothing parameters, subjective judgment was employed.

For the present study, a digital filter cut-off frequency of 10 Hz was selected as best producing reasonably smooth and realistic curves in all the trials analyzed. This choice implies that any motion having a harmonic content greater than 10 Hz is largely excluded from the calculations of handle forces and kickback energy. Some of the trials digitized from the better quality films could have been filtered with a higher cut-off frequency, but for the sake of providing a basis for comparisons, all trials were filtered with the same cut off frequency.

With regard to the type of filtering employed by the Biomechanics Laboratory, it has become recognized in biomechanically related applications that digital filtering and spline fitting techniques are superior to the use of polynomials. Digital filtering or cubic spline fitting do not impose specific mathematical forms on the function to be smoothed. In the Biomechanics Laboratory analysis, a second order Butterworth filter having an adjustable cut-off freuency was utilized. The filter is a recursive one (two previously smoothed values are used to calculate the smoothed value of a point) and this necessitates a forward and backward pass over the interval to remove the phase shift which results from just a single pass. Further discussion of this technique is given in References [5] and [7].

In the evaluation of the Association analytical model, two of the kickback variables which must be computed are the forces and moments which are developed at the handles of a hand-held test saw during a simulated kickback. When a comparison was made of the computed hand forces and moments determined by the Biomechanics Laboratory with those determined by CSMA for ten kickback trials, some discrepancies were observed, primarily during approximately the first 30 milliseconds after the test saw exited from a wood specimen. Since the

Association employed polynomial smoothing techniques, it has been suggested that the latter discrepancies are probably due to the different smoothing techniques employed in the analyses. On the basis of comparison of the kickback energy components computed by the Association and the Biomechanics Laboratory for ten trials, it would appear that the different values for the hand forces and moments during the initial portion of a kickback may not be of fundamental significance. Further examination of this question would require that special computations be performed using the analytical model in order to establish the sensitivity of the computed angles of kickback motion to variability in the hand forces and moments.

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For the past several years, NBS has supported the Consumer Product Safety Commission (CPSC) in the development of a performance standard to address the kickback hazard for chain saws. This process included participation of the Chain Saw Manufacturers Association (CSMA), CPSC, and NBS in the development of kickback testing equipment and procedures and the study of operator/saw interactions during simulated kickback trials. The present report describes an evaluation of the CSMA and CPSC procedures for simulating "Classical" or rotational kickback motion based primarily on analyses of high-speed films of kickback trials, the development of test procedures for simulating "pinch" or linear kickback motion, and the simulation of kickbacks for the actuation of chain brake systems for chain saws. Included in the report is a discussion of important kickback test parameters such as mechanical energy, saw inertia, handle spacing and the interrelationships among the various parameters.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

chain-saw kickback motion; chain brake actuation; film analyses; handle spacing; kickback energy; linear kickback; performance standard; rotational kickback; simulated kickback modes.

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