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Evaluation of Chain Saw Kickback Motion Using an Optoelectronic Measurement System

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Center for Manufacturing Engineering
Mechanical Production Metrology Division
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Report to
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1. Introduction

Background

In 1978, the Consumer Product Safety Commission (CPSC) accepted a proposal from the Chain Saw Manufacturers' Association (CSMA) to develop a voluntary performance standard to address the kickback hazard for chain saws. The process included participation by CPSC, the National Bureau of Standards (NBS), consumers, and industry 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 kickback research at NBS in the joint effort with CPSC and the chain saw industry is given in Reference [1].

In 1980 the CPSC decided to initiate the in-house development of a mandatory standard to address chain saw kickback. Part of that effort involved relating known chain saw energy levels generated during kickback in the KBM to the final angle that a saw might travel when held in the hands of a chain saw operator. The present report describes the experimental program developed at NBS 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. The measurement system employed in this research included a computer-controlled optoelectronic system for measuring the displacements of selected points on the test saws, test fixture, and the right arm motion of selected test subjects during simulated kickbacks. Included in the report is a description of the test equipment and procedures, the experimental design, and analyses of the measured displacement data for chain saws having known values of kickback energy.

2. Kickback Test Arrangement

In order to establish the relationship of energy during a simulated kick-back to the kickback angle of a saw in the hands of a chain saw user, it was necessary to develop a suitable test fixture and outline the procedures before making the appropriate measurements. A KBM had been developed and shown in prior investigations by both NBS and the chain saw industry to simulate kickback conditions in a reproducible manner for determining the energy associated with chain saw kickback motion.[1] Thus, the procedures successfully implemented for the KBM formed the basis for developing a test fixture for hand-held tests of simulated kickbacks in the present investigation.

Kickback is initiated in the KBM by accelerating a carriage, holding a "wood" (i.e., medium density fiberboard) specimen, into contact with the moving saw chain on the upper quadrant of the saw guidebar nose. The method selected to accelerate the carriage, control its approach speed, and adjust the specimen contact angle for the hand-held tests was the same as that used in the KBM [1]. Figure 1 shows the fixture and test arrangement for the kickback experimental program.

In the hand-held kickback investigations, volunteer test subjects were required to hold an operating test saw in a simulated bucking mode of operation. (This procedure will be discussed in a later section.) During preliminary kickback tests, it was found necessary to constrain the rearward carriage motion as the kickback was initiated in order to adequately transfer the carriage momentum to the test saw via the wood-saw interaction. The test carriage momentum in the KBM is efficiently transferred to the test saw since the

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[1]The Round Robin I kickback tests which demonstrated the interlaboratory reproducibility are discussed [1].
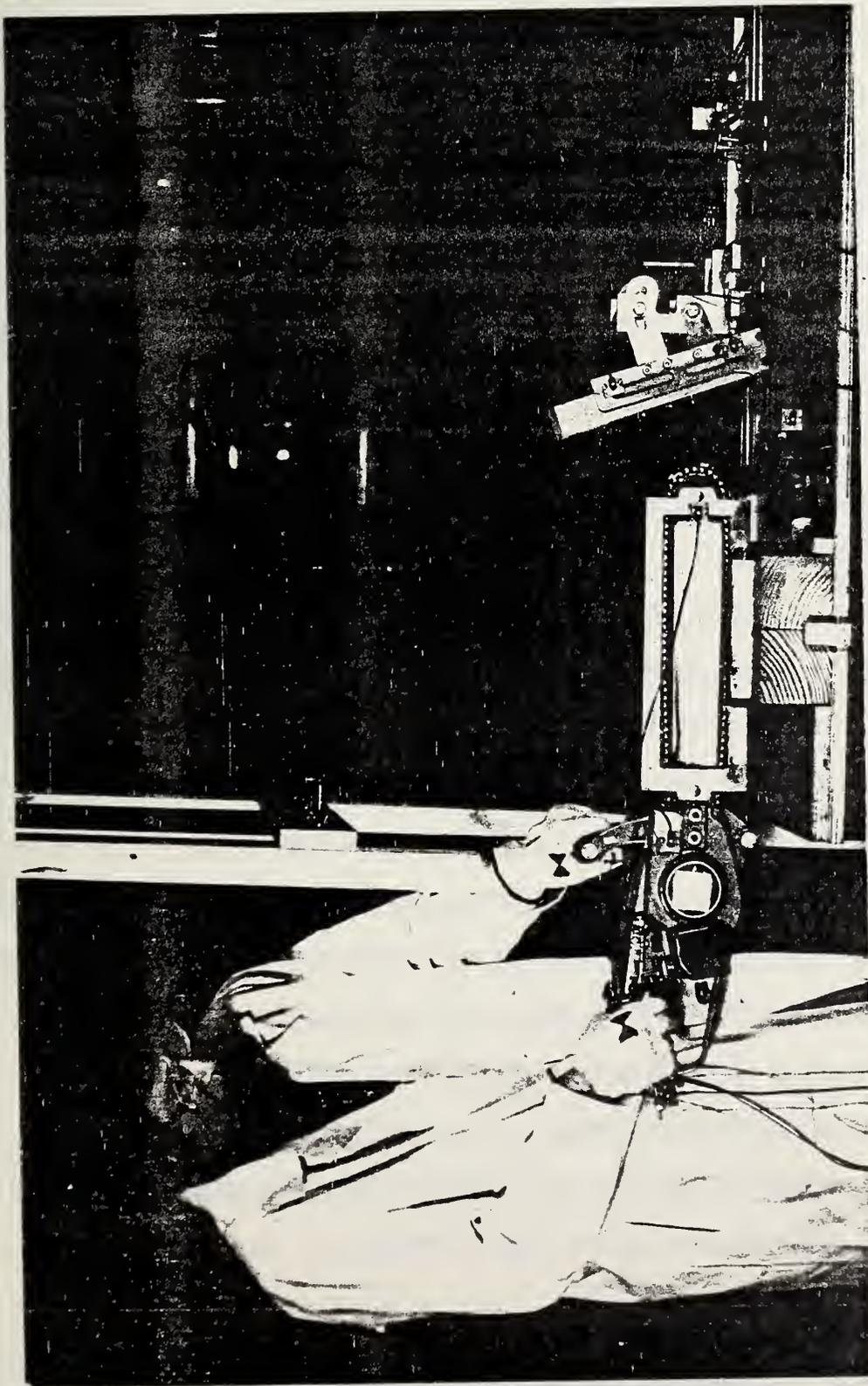
Figure 1. Test Arrangement for Kickback Experimental Program

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saw can only rotate about its center of gravity during kickback; i.e., the saw is constrained so that no lateral motion is permitted. Similar constraint of a test saw's initial motion during the hand-held kickback simulation of a bucking operation was considered, but was judged to be overly restrictive. The use of a pawl and rack mechanism in the test fixture to constrain the carriage's initial rearward motion was found to effectively transfer the carriage momentum to the saw without unrealistically constraining the test saw.

The initial horizontal position of a test saw in the KBM was controlled in a manner which prevented downward motion of the guidebar during a kickback test. For the hand-held test arrangement, the chain saw motion was similarly controlled by using a lightweight shield surrounding the flat portion of the guidebar as shown in figure 1. (Another purpose of the shield was to protect the test subjects[1]). This procedure served both to simulate a bucking mode of operation, wherein a log is cut by the chain on the straight portion of the guidebar, and to control the initial horizontal position of the guidebar to insure that the wood-saw contact angle was properly maintained.

The horizontal alignment of the guidebar shield, which rested on a wooden block, was monitored by the principal investigator during each kickback test. Immediately prior to the release of the test carriage to initiate a kickback, a technician would signal the test subject to adjust the saw alignment if necessary to insure that the guidebar was properly aligned in a vertical plane. The initial guidebar alignment in the vertical and horizontal planes was necessary in order to reproduce the same initial conditions as achieved during kickback tests in the Kickback Test Machine.

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[1] A full discussion of the various safety precautions, which included a barrier to prevent excessive rotational saw motion is given in Appendix A.

3. Optoelectronic Measuring System

An optoelectronic tracking system was used to measure x and y coordinates in real time at preselected locations on a test saw, the test fixture, and on several of the volunteer operators during the kickback experimental program.[2] Small light-emitting diodes (LED's) were attached to each test saw near the guidebar nose, the center of gravity, the rear handle, and at three other positions of interest on the test fixture or on the right arm of an operator. Figure 1 shows the typical test arrangement; for several tests, the diodes on the wood carriage were placed on the wrist and elbow of the operator.

The main component of the computer-controlled optoelectronic system is a specially-developed infrared camera having an analogue photodetector with four electrodes. When the infrared light from an LED is focused on the detector surface through the camera lens system, the generated photocurrent is divided among the four electrodes. The current is used to obtain two signals which are linearly related to the x and y coordinates of the LED. The resolution of the system digital output is specified as 1 part in 1024 (i.e., 10 bits).

For the kickback experimental program, the detector was used to measure the position of six LED's.[3] This was achieved by turning the LED's on and off at a rate of 312 Hz. Thus, the time was 0.0032 sec. interval between successive tracking cycles measured during a kickback. The image field was scanned so that the x and y coordinates for each LED point location could be digitized and stored in a mini-computer memory for data reduction and analysis. The displacement data were visually observed on a video terminal following the first kickback test for each saw in order to check that the recording

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[2] The Selspot optoelectronic system was used in this investigation.
Note: Commercial instruments and products are identified in this report in order to specify adequately the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the equipment identified is necessarily the best available for the purpose.

[3] A maximum of 30 LED's can be tracked in one cycle.

system was properly triggered. Coordinate-time data were stored on floppy disks, and a hard copy was subsequently printed to enable the kickback motion to be analyzed as described in other sections of this report.

4. Experimental Program

4.1. Selection of Test Saws

The CPSC provided 34 consumer-type chain saws from which to select saws for the experimental program. From this population of currently-manufactured saws, 5 gasoline and 2 electric chain saws were selected. Preliminary selection of the test saws was based only on the total kickback energy determined by CPSC with the Kickback Test Machine. Since some of the saws in this group were found to have relatively little kickback motion when held by each of several operators, a second group of saws was chosen taking into account the polar moment of inertia of the saw in addition to its kickback energy characteristics. The final selection took into account additional design features which provided somewhat greater diversity among the test saws. The general characteristics of the saws selected for the kickback experimental program are listed in table 1.

4.2. Kickback Test Conditions

During the preliminary hand-held kickback tests to select the test saws for the experimental program, the saws were tested at conditions where the total energy obtained in the KBM was found to be maximum. After the test saws were selected, it was found that somewhat larger kickback motion would result if the saws, when held by an operator, were tested at conditions where the rotational energy obtained in the KBM was at a maximum.

A list of the kickback test parameters which were used for the chain saws in the experimental program is given in table 2. The maximum values for rotational energy as determined in the KBM are also noted in this table.

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Table 1. Characteristics of chain saws in hand-held kickback
experimental program

Chain Saw[1]	Weight N (lbf)	Guidebar Length[2] cm (in)	Chain Type	Polar Inertia m-N-sec^2 (in-lbf-sec^2)	Total Energy[3] joule (in-lbf)
G1 (1.6)	2.270 (10.10)	30.48 (12)	Low Profile	0.0617 (0.546)	12.6 (112)
G2 (2.0)	2.172 (9.66)	30.48 (12)	Low Profile	0.0651 (0.576)	13.6 (120)
G3 (2.1)	2.934 (13.05)	35.56 (14)	Low Profile	0.0942 (0.834)	10.7 (95)
G4 (2.6)	2.967 (13.20)	40.64 (16)	Standard	0.1321 (1.169)	36.3 (321)
G5 (3.6)	3.992 (17.76)	40.64 (16)	Standard	0.1527 (1.351)	51.8 (458)
E6 (2.25)	2.423 (10.78)	35.56 (14)	Low Energy	0.0584 (0.517)	9.6 (85)
E7 (2.0)	2.774 (12.34)	35.56 (14)	Top Sharp	0.0817 (0.723)	11.9 (105)

[1] For gasoline-powered saws, designated by "G," the number in parentheses represents the engine cubic-inch displacement. For electric-powered saws, designated by "E," the number in parentheses represents the engine horsepower capacity.

[2] All the guidebars were equipped with a sprocket nose, and each of the latter were symmetric except for Saw E7.

[3] The kickback energy was measured in the Kickback Test Machine at those conditions producing the maximum value of rotational energy. The same test conditions were used in the hand-held kickback program and are given in table 2.

Table 2. Test parameters for the hand-held kickback experimental program[1]

Test Saw	Rotational Energy[2] joule (in-lbf)		Contact Angle (deg)	Engine Speed (rpm)	Approach Speed (in/sec)
G1	9.5	(84)	20	10,000	30
G2	11.1	(98)	15	11,000	35
G3	9.7	(86)	15	11,000	35
G4	32.5	(288)	15	9,500	25
G5	46.7	(413)	10	11,500	30
E6	8.6	(76)	20	7,200	20
E7	8.7	(67)	10	7,200	35

[1] The warm-up, clutch-burn or torque, and chain-tension procedures for the hand-held saws were the same as the test procedures developed for use with the Kickback Test Machine. The test saws and chains were broken in by the CPSC prior to conducting the hand-held experimental program.

[2] Determined by CPSC using the Kickback Test Machine.

4.3. Volunteer Test Operators

A total of 9 male and 2 female volunteers served as test operators in the hand-held kickback program. Selection of the volunteer subjects and other human factors aspects of the experimental design for the program were developed under the guidance of a research psychologist. Detailed information concerning the latter topics, including the test subject profiles, are given in Appendix B.

Prior to testing, the principal investigator orally gave each subject the following instructions, which had been prepared by a research psychologist:

"It is very important that you understand the following instructions:

 What we want you to do is to pretend that you are cutting a log. Let the chain saw rest on the wooden block and pretend it is cutting its way through it. Do not lean into or push down on the saw. When you get the saw in the correct position, just hold it steady. Do you have any questions?"

Prior to the tests for each saw, the principal investigator demonstrated a kickback for that particular saw. The safety bar height was then adjusted so that the subject could not see when the wood carriage was released to initiate the kickback motion. The subject was given an opportunity to experience several kickbacks as part of the indoctrination before the kickback motion was measured for five consecutive tests for each saw.

5. Determination of Test Saw Rotational Displacements

For most of the kickback tests, the LED's, whose coordinates were measured in real time during a kickback, were placed on both the test saw and the test fixture. Three diodes were always located on the test saw: a) on the guidebar shield near the nose tip of the guidebar, b) near the saw center of gravity, and c) near the rear handle of the saw. Usually, three diodes were also located on the test fixture, one at a fixed reference position at the base of the carriage rails and two on the clamp of the moving carriage.

The primary purpose of the reference diode at the base of the carriage rails was to ensure that the camera set up of the measuring system was the same for the various tests, since the instrumentation was frequently disassembled after a test and reassembled for succeeding tests.[4] The purpose of the diodes mounted on the carriage clamp was to check the angle of the wood specimen and to monitor the carriage motion during the kickback. Since the contact angle and carriage speed were accurately measured with other equipment, the coordinate data at these positions were additional indicators that these parameters were correctly adjusted. For several of the kickback tests, the diodes were removed from the carriage clamp and placed on the wrist and elbow of the test subject. The coordinate data for these positions were then used to plot the motion of the right-arm wrist and elbow for several of the larger male test subjects. This information was used in an evaluation of the motion produced in the Human Factors Apparatus (HFA), the data for which will be presented in a separate report [2].

The coordinate-time data for the diodes mounted on the test saws were analyzed in this investigation. Primary emphasis was placed on evaluation of the saw rotation, because of the severity of kickback injuries associated with such displacements [3].

Criteria and Method for Assessing the Kickback Angle. The method for assessing the kickback angle for this preliminary analysis was chosen on the basis of the CPSC evaluation of the apparent angle of rotation from in-depth investigation reports (IDIR's) of chain-saw accidents. This angle is measured as though a saw rotates about a point in line with the top of the guidebar at point a on that line (line A) where it is intersected by another line (line B) perpendicular to it and

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[4]The instrumentation was required for another research activity which ran concurrently with the kickback experimental program.

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touching the rearmost part of the rear handle (see figure 2). Another line is then drawn from this point to the point of chain contact with the operator (line C), as shown. The angle from line A lying along the top of the guidebar to line C about point a was measured in the IDIR's as the apparent angle of rotation. This approach was developed by the CPSC as a measure of the difference between the position of the saw just prior to kickback and the location of the body part injured.

This criterion for assessing the apparent kickback angle implies that the operator's right hand continues to grip the saw's rear handle for the duration of the kickback. There was no method for evaluating this assumption prior to conducting the experimental program. Other postulated methods for assessing the kickback angle depended similarly on assumptions which could not be evaluated prior to conducting the experimental program.

In the analysis of the saw LED (diode) coordinate data to compute the derived angle of rotation (DAR), a correction was made so that the rear handle diode position was adjusted to lie along line B in figure 2. A second correction was made to account for the fact that the diode at the end of the guidebar was, in general, not aligned with the rear handle diode. Although other modifications to the recorded data were omitted for this preliminary analysis, an estimate was made of their influence on the kickback angles. These second-order corrections will be discussed in a later section of this report. It should be noted that the operator's control of the saw for the CPSC kickback angle criterion, based upon IDIR's, was confirmed during the experimental program: the test subjects maintained right-hand grip of the rear handle throughout the kickback for all the tests.

The derived angle of rotation (DAR) was determined from the digitized coordinate data as follows:

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POINT OF CONTACT WITH BODY

APPARENT ANGLE OF ROTATION

C

A

B

a
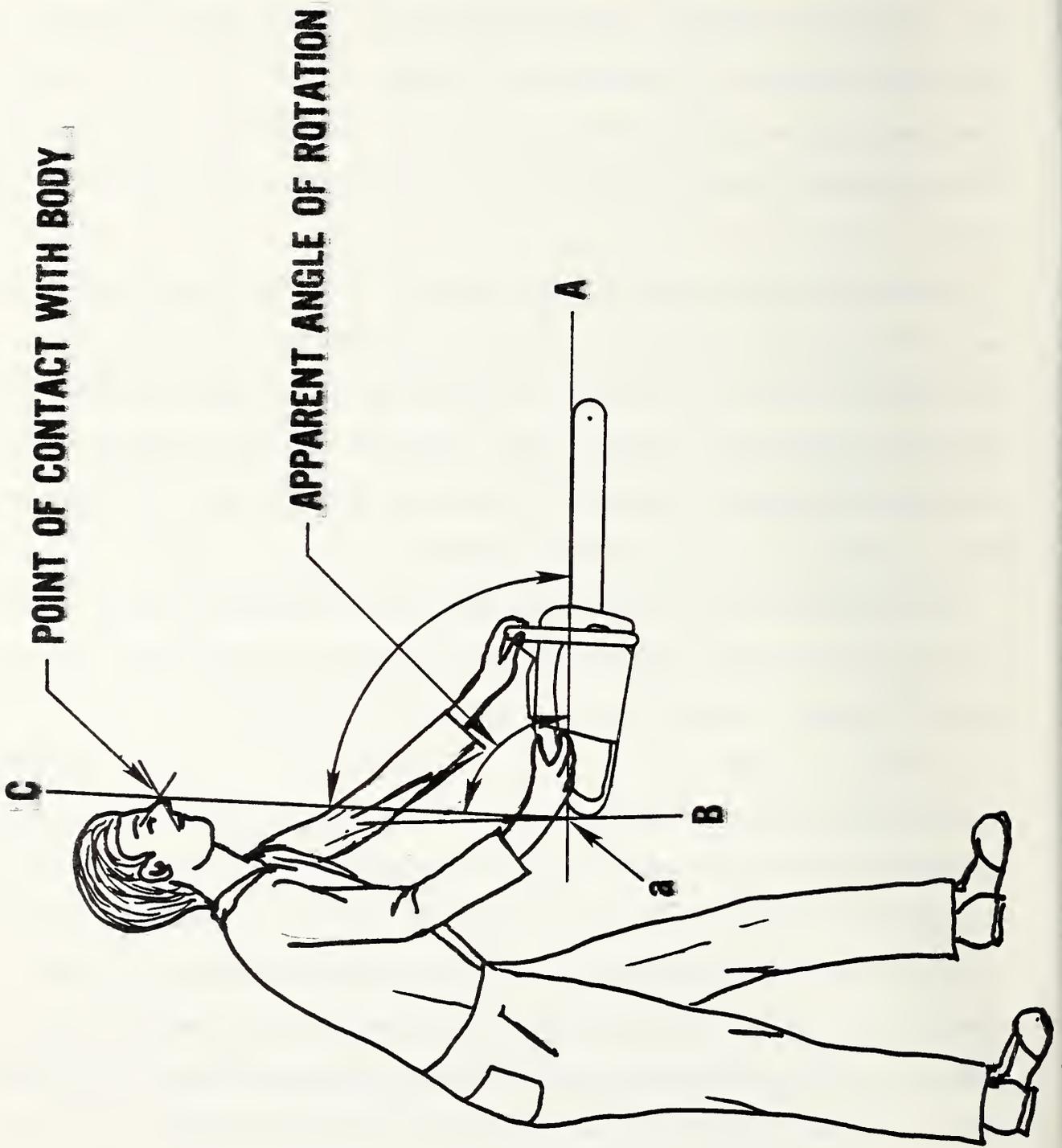
Figure 2. CPSC Determination of Apparent Kickback Angle of Bumper

$$DAR = DAR_1 + DAR_2,$$

where DAR_1 is the angle through which the guidebar rotates above a horizontal line passing through the rearmost part of the rear handle, i.e., (X_{50}, Y_{50}) as shown in figure 3. Since the diode located at the end of the guidebar, having coordinates (X_3, Y_3), was generally not located on this horizontal line when the saw was held as the kickback was initiated, the term DAR_2 was added to DAR_1 to incorporate the angular travel of this diode before it reached the horizontal. The complete equation is:

$$DAR = \tan^{-1}[(Y_3-Y_{50})/(X_{50}-X_3)] + \tan^{-1}[(Y_{50}-Y_{30})/(X_{50}-X_{30})]$$

where (X_{30}, Y_{30}) are the diode coordinates at the end of the guidebar at initiation of kickback (time $t = 0$); the sign conventions for the displacement measuring system are shown in figure 3.

Before the derived angle of rotation could be computed, it was first necessary to determine when the test saw was contacted by the wood specimen. The best indication was vertical motion recorded from the diode placed near the tip of the saw guidebar. Contact with the wood occurred just prior to the first indication of guidebar vertical motion. Thus, the displacements measured for the diode positions one measurement sample (0.003 sec) prior to the latter motion were taken to define the initial diode coordinates as contact was made. The coordinate data were printed out in units of the optoelectronic measurement system, which were subsequently used to estimate the derived angles of rotation for an initial analysis.

Since the diode located near the rear handle of each test saw was not precisely in the desired reference position, a correction was made to the initial coordinates for this diode to compute the kickback angles as shown in figure 3.
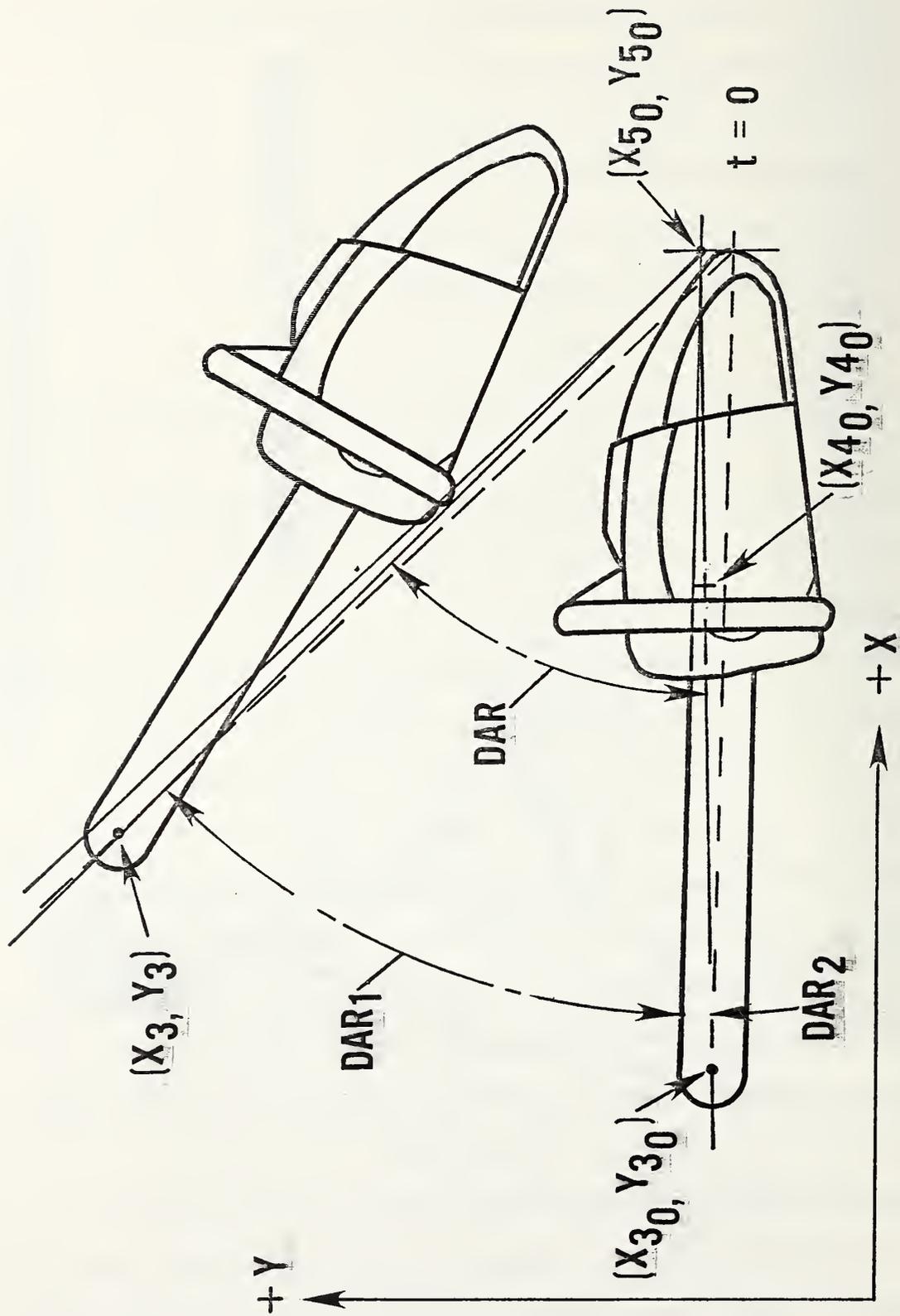
Figure 3. Diode Coordinates and Sign Convention for Computing DAR

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Similar corrections to the other diode positions on the guidebar, the saw, and at its center of gravity, were estimated to have a minor influence on the computed angle of rotation about the rear handle. These corrections and other second-order factors were investigated by computer analyses of the displacement data for Test Subjects CDS and NB which are given in Appendix C.

A summary of the computed DAR (derived angle of rotation), for each of the hand-held kickback tests, is given in tables 3 through 9.[1] In addition to the values for DAR, the average DAR for each data set (5 tests) is given, along with the standard deviation and coefficient of variation. Following the same convention used in analyses of KBM kickback data, the coefficient of variation is defined as the standard deviation divided by the average value for each data set.

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[1] There were 11 test subjects who participated in the Test Series 1 kickback tests; replicate tests for 7 of these subjects were conducted during Test Series 2. Additional information pertaining to the subject treatment and other human factors considerations is presented in Apendix B.

Table 3. Computed values of kickback derived angle of rotation (DAR) for Saw G1

Test Series	Test Subject	DAR for Replicate Tests, deg					Average DAR, deg	Standard Deviation	Coefficient of Variation
		1	2	3	4	5			
1	CS	5R[1]	3R	7R	1R	6R	4.4	2.41	0.55
	CK	7R	19R	16R	11F	7F	12.0	5.38	0.45
	CR	25R	24R	7R	10R	15R	16.2	8.10	0.50
	CN	16F	15F	10F	13F	10F	12.8	2.77	0.22
	CJ	9R	21R	11R	18F	13F	14.4	4.97	0.34
	CD	16F	13F	17F	11R	8R	13.0	3.67	0.28
	CMJ	19F	16F	15F	19R	15R	16.8	2.05	0.12
	CA	44R	[2]	[2]	[2]	29F	--	--	--
	NB	14R	16R	12R	10R	11R	12.6	2.41	0.19
	CDS	26F	27F	30F	[2]	26F	27.2	1.89	0.07
	CHD	43F	18F	19F	16F	13F	21.8	12.07	0.55
2	CDS	24F	29F	17F	27F	20F	23.4	4.93	0.21
	CR	22F	15F	35F	25F	18F	23.0	7.71	0.34
	CJ	27F	35F	25F	39F	27F	30.6	6.07	0.20
	CHD	26R	28R	23R	24R	25R	25.2	1.92	0.08
	CN	11F	10F	14F	15F	10F	12.0	2.34	0.20
	NB	17R	21R	13R	18R	16R	17.0	2.92	0.17
	CD	41R	23R	25R	34R	[2]	30.7	8.34	0.27

Average coefficient of variation for 17 tests was 0.28.

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[1]Right-hand on rear (R) or front (F) throttle trigger.

[2]Malfunction of recording system occurred during the test which interrupted the data transfer to the computer memory.

Table 4. Computed values of kickback derived angle of rotation (DAR) for Saw G2

Test Series	Test Subject	DAR for Replicate Tests, deg					Average DAR, deg	Standard Deviation	Coefficient of Variation
		1	2	3	4	5			
1	CS	19	26	35	20	26	25.2	6.38	0.25
	CK	18	19	14	18	19	17.6	2.07	0.12
	CR	15	14	19	16	14	15.6	2.07	0.13
	CN	19	14	29	16	17	19.0	5.87	0.31
	CJ	23	17	16	19	21	19.2	2.86	0.15
	CD	15	14	[1]	10	14	13.2	2.22	0.17
	CMJ	37	16	29	12	26	24.0	10.07	0.42
	CA	19	14	23	20	22	19.6	3.51	0.18
	NB	11	15	14	15	13	13.6	1.67	0.12
	CDS	37	21	27	30	25	28.0	6.00	0.21
	CHD	17	27	22	23	20	21.8	3.70	0.17
2	CDS	32	30	34	19	29	28.8	5.80	0.20
	CR	16	18	13	17	10	14.8	3.27	0.22
	CJ	17	14	14	12	16	14.6	1.95	0.13
	CHD	30	27	24	27	20	25.6	3.78	0.15
	CN	15	14	18	10	15	14.4	2.88	0.20
	NB	25	15	28	17	15	20.0	6.08	0.30
	CD	17	22	14	16	14	16.6	3.29	0.20

Average coefficient of variation for 18 tests was 0.20.

[1]Malfunction of recording system occurred during the test, which interrupted data transfer to the computer memory.

Table 5. Computed values of kickback derived angle of rotation (DAR) for Saw G3

Test Series	Test Subject	DAR for Replicate Tests, deg					Average DAR,deg	Standard Deviation	Coefficient of Variation
		1	2	3	4	5			
1	CS	22	10	17	28	24	20.2	6.94	0.34
	CK	14	14	17	13	13	14.2	1.64	0.12
	CR	10	14	14	16	18	14.4	2.97	0.21
	CN	10	13	12	12	14	12.2	1.48	0.12
	CJ	14	7	15	13	11	12.0	3.16	0.26
	CD	18	16	16	22	23	19.0	3.32	0.17
	CMJ	18	14	30	24	20	21.2	6.10	0.29
	CA	11	14	16	14	21	15.2	3.70	0.24
	NB	12	8	11	14	11	11.2	2.17	0.19
	CDS	20	17	23	31	32	24.6	6.65	0.27
	CHD	23	21	26	22	20	22.4	2.30	0.10
2	CDS	32	41	26	27	26	30.4	6.43	0.21
	CR	18	17	15	17	15	16.4	1.34	0.08
	CJ	16	15	14	14	14	14.6	0.89	0.06
	CHD	20	25	22	24	25	23.2	2.17	0.09
	CN	11	18	18	21	20	17.6	3.91	0.22
	NB	21	23	16	18	12	18.0	4.30	0.24
	CD	16	17	23	22	22	20.0	3.24	0.16

Average coefficient of variation for 18 tests was 0.19.

Table 6. Computed values of kickback derived angle of rotation (DAR) for Saw G4

Test Series	Test Subject	DAR for Replicate Tests, deg					Average DAR, deg	Standard Deviation	Coefficient of Variation
		1	2	3	4	5			
1	CS	39	34	31	24	26	30.8	6.06	0.20
	CK	15	14	14	18	15	15.2	1.64	0.11
	CR	41	40	30	34	44	37.8	5.67	0.15
	CN	35	41	33	29	41	35.8	5.22	0.14
	CJ	32	24	23	24	30	26.6	4.10	0.15
	CD	25	18	26	30	34	26.6	5.98	0.22
	CMJ	48	28	32	34	28	34.0	8.25	0.24
	CA	36	36	36	24	41	34.6	6.31	0.18
	NB	39	37	44	41	31	38.4	4.88	0.13
	CDS	52[1]	49	36	36	51[1]	44.8	8.10	0.18
	CHD	39	32	40	33	36	36.0	3.54	0.10
2	CDS	50[1]	52[1]	30	35	43	42.0	9.46	0.22
	CR	28	46	38	26	48[1]	37.2	10.06	0.27
	CJ	31	35	33	31	32	32.4	1.67	0.05
	CHD	41	38	45	47	33	40.8	5.58	0.14
	CN	41	38	34	38	32	36.6	3.58	0.10
	NB	48	46	34	41	35	40.8	6.30	0.15
	CD	[2]	24	34	20	25	25.8	5.91	0.23

Average coefficient of variation for 18 tests was 0.16.

[1] Saw struck safety bar.

[2] Malfunction of recording system occurred during the test, which interrupted the data transfer to the computer memory.

Table 7. Computed values of kickback derived angle of rotation (DAR) for Saw G5

Test Series	Test Subject	DAR for Replicate Tests, deg					Average DAR, deg	Standard Deviation	Coefficient of Variation
		1	2	3	4	5			
1	CS	8	16	13	10	19	13.2	4.44	0.34
	CK	25	25	25	23	12	22.0	5.66	0.26
	CR	33	36	38	34	37	35.6	2.07	0.06
	CN	46	47	45	38	34	42.0	5.70	0.14
	CJ	32	27	18	20	24	24.2	5.58	0.23
	CD	15	16	37	9	16	18.6	10.69	0.57
	CMJ	23	13	16	22	15	17.8	4.44	0.25
	CA	37	30	25	25	29	29.2	4.92	0.17
	NB	21	51[1]	43	35	22	34.4	13.07	0.38
	CDS	47	32	51[1]	49[1]	48	45.4	7.64	0.17
	CHD	42	26	29	41	30	33.6	7.37	0.22
2	CDS	49[1]	49[1]	51[1]	52[1]	47	49.6	1.95	0.04
	CR	41	42	34	32	28	35.4	5.98	0.17
	CJ	32	37	35	47	36	37.4	5.68	0.15
	CHD	41	42	49	42	37	42.2	4.32	0.10
	CN	39	45	36	28	25	34.6	8.14	0.24
	NB	53	57	32	45	28	43.0	12.71	0.30
	CD	18	33	14	22	24	22.2	7.16	0.32

Average coefficient of variation for 18 tests was 0.23.

[1]Saw struck safety bar.

Table 8. Computed values of kickback derived angle of rotation (DAR) for Saw E6

Test Series	Test Subject	DAR for Replicate Tests, deg					Average DAR, deg	Standard Deviation	Coefficient of Variation
		1	2	3	4	5			
1	CS	7	12	9	13	12	10.6	2.52	0.24
	CK	5	2	3	4	4	3.6	1.14	0.32
	CR	10	8	7	8	9	8.4	1.14	0.14
	CN	6	7	14	10	11	9.6	3.21	0.33
	CJ	6	13	12	13	11	11.0	2.92	0.26
	CD	22	16	18	14	23	18.6	3.85	0.21
	CMJ	17	27	26	29	17	23.2	5.76	0.25
	CA	18	26	16	16	27	20.6	5.46	0.26
	NB	9	10	10	8	13	10.0	1.87	0.19
	CDS	21	22	26	26	22	23.4	2.41	0.10
	CHD	9	7	7	18	17	11.6	5.46	0.47
2	CDS	17	16	19	16	18	17.2	1.30	0.08
	CR	15	8	9	10	10	10.4	2.70	0.26
	CJ	13	14	13	13	11	12.8	1.10	0.08
	CHD	23	18	22	16	14	18.6	3.85	0.21
	CN	9	10	10	7	12	9.6	1.82	0.19
	NB	16	18	15	19	11	15.8	3.11	0.20
	CD	12	15	16	20	12	15.0	3.32	0.22

Average coefficient of variation for 18 tests was 0.22.

Table 9. Computed values of kickback derived angle of rotation (DAR) for Saw E7

Test Series	Test Subject	DAR for Replicate Tests, deg					Average DAR, deg	Standard Deviation	Coefficient of Variation
		1	2	3	4	5			
1	CS	9	21	20	10	25	17.0	7.11	0.42
	CK	10	13	35	9	10	15.4	11.06	0.72
	CR	8	8	8	10	12	9.2	1.79	0.19
	CN	13	10	11	10	15	11.8	2.17	0.18
	CJ	12	11	15	10	8	11.2	2.59	0.23
	CD	21	18	14	15	14	16.4	3.05	0.18
	CMJ	25	12	16	16	14	16.6	4.98	0.30
	CA	27	42	27	[1]	[1]	32.0	8.66	0.27
	NB	18	32	24	8	10	18.4	9.94	0.54
	CDS	14	14	18	13	31	18.0	7.52	0.42
	CHD	15	9	16	14	13	13.4	2.70	0.20
2	CDS	11	20	21	11	17	16.0	4.80	0.30
	CR	7	12	10	12	7	9.6	2.51	0.26
	CJ	12	12	16	9	15	12.8	2.77	0.22
	CHD	27	23	17	19	18	20.8	4.15	0.20
	CN	9	7	12	20	9	11.4	5.13	0.45
	NB	6	8	10	14	10	9.6	2.97	0.31
	CD	21	28	14	31	42	27.2	10.57	0.39

Average coefficient of variation for 18 tests was 0.32.

[1]Malfunction of recording system occurred during the test which interrupted data transfer to the computer memory.

6. Principal Test Results

6.1. Kickback Energy During Hand-Held Tests

One of the principal objectives in the experimental program was to relate the kickback angle through which a chain saw might travel when held by an operator to the kickback energy determined for the saw in the Kickback Test Machine (KBM). Since the test conditions during the hand-held kickbacks were based on KBM energy data, it was desirable to determine as well as possible the kinetic energy achieved during the hand-held kickback tests. It should be emphasized that the accuracy of conclusions drawn from kinematic studies of motion depends heavily upon the accuracy of the displacement measurements which are the precursors for calculation of such quantities as the energy [4].

An initial attempt, using high-speed photography, was made to estimate the kickback energy for a hand-held saw based on evaluating the saw displacements for a kickback filmed at a speed of 300 frames per second. This estimate did not compare well with the energy determined for that saw during a simulated kickback in the KBM under the same test conditions. The major sources of inaccuracy were the relatively slow frame speed and the difficulty in visually analyzing the data from film. It was also recognized that the very small displacements associated with the initial kickback motion of the test saw center of gravity made the estimation of lateral and vertical energy components difficult without sophisticated measurement and analysis of the saw powerhead motion. Although a better estimate of the rotational energy component for a test saw was achieved by filming a kickback at a speed of 500 frames per second, the estimation of the other energy components was not greatly enhanced. As noted by other investigators, attempts to calculate velocities (required to determine the energy) by differentiation of displacements have been plagued by amplification of the noise inherent in even apparently smooth displacement data [4].

The use of an optoelectronic system for measuring the kickback motion in the present experimental program permitted a more reliable estimate to be made for the rotational energy for some kickback tests. The source of error due to visual analysis of film is eliminated, but the noise associated with very small displacements of the saw powerhead was not greatly improved. The standard sampling rate of 312 Hz for the optoelectronic measuring system was sufficient to enable good estimates to be made for saw rotational velocities, at least for the test saws having large kickback motion when held by relaxed test subjects. Attempts made to increase the standard sampling rate were unsuccessful due to the inability to multiplex the number of LED positions required.

The estimates of rotational energy for each of the test saws and the rotational energy obtained with the KBM for the saws at the same test conditions are given in table 10. The values in this table were computed for test conditions where the duration of the kickback per degree of rotation indicated that the test subject was relatively relaxed.[5] In this regard, it is evident that a large amount of energy can be absorbed if the saw motion deviates from a planar path (planar motion is ensured in the KBM by constraint of a test saw). Thus, the estimates of rotational energy are in best agreement with the known energy values when the test subject does not impose constraints on the rotational motion of the saw that differ substantially from those in the KBM.

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[5]Typical values for this index found by a major saw manufacturer were in the range of 0.002 to 0.005 sec per degree.

Table 10. Estimated rotational kickback energy for saws during hand-held tests.

Test Saw	Rotational Energy Determined in KBM joule (in-lbf)		Estimated Rotational Energy in Hand-Held Tests[1] joule (in-lbf)	
G1	9.5	(84)	6.8	(60)
G2	11.1	(98)	8.4	(74)
G3	9.7	(86)	8.4	(74)
G4	32.5	(288)	27.0	(239)
G5	46.7	(413)	42.1	(373)
E6	8.6	(76)	7.6	(67)
E7	7.6	(67)	7.2	(64)

[1]Energy estimated from $I\omega^2/2$ where I is the measured polar moment of inertia about the saw c.g. and ω is the maximum rotational velocity determined from optoelectronic displacement data. The velocity was estimated during the initial kickback motion (while the chain was in contact with the wood specimen) and only the inertia due to the saw was considered.

6.2 Comparison of Saw Motion with Energy Measured in Kickback Machine

In order to compare the chain saw rotational motion measured during the hand-held kickback tests with the energy measured for the test saws in the kickback machine, it is useful to average the computed kickback angles. The average and maximum values for the derived angle of rotation (DAR) for each test subject and saw are presented in tables 11 and 12 for the first 11 kickback tests (Test Series 1) and the last 7 tests (Test Series 2), respectively. A tabulation of the composite mean and maximum DAR values for Test Series 1 and 2 is given in table 13.

Comparison of the Series 1 and 2 data in the latter table indicates there was probably some effect from subjects learning on saw kickback, particularly for saws G1, G4 and G5. The total kickback energy and rotational components of energy for the test saws determined using the kickback machine are given in the last column of the table.

Table 11. Summary of average and maximum values of derived angle of rotation (DAR) for kickback test series 1.

Test Subject	Kickback Angle	DAR, deg						
		G1	G2	G3	G4	G5	E6	E7
CS	Average	4	25	20	31	13	11	17
CS	Maximum	7	35	28	39	19	13	25
CK	Average	12	18	14	15	22	4	15
CK	Maximum	19	19	17	18	25	5	35
CR	Average	16	16	14	38	36	8	9
CR	Maximum	25	19	18	44	38	10	12
CN	Average	13	19	12	36	42	10	12
CN	Maximum	16	29	14	41	47	14	15
CJ	Average	14	19	12	27	24	11	11
CJ	Maximum	21	23	15	32	32	13	15
CD	Average	13	13	19	27	19	19	16
CD	Maximum	17	15	23	34	37	23	21
CMJ	Average	17	24	21	34	18	23	17
CMJ	Maximum	19	37	30	48	23	29	25
CA	Average	[1]	20	15	35	29	21	32
CA	Maximum	44	23	21	41	37	27	42
NB	Average	13	14	11	38	34	10	18
NB	Maximum	16	15	14	44	51	13	32
CDS	Average	27	28	25	45	45	23	18
CDS	Maximum	30	37	32	52	51	26	31
CHD	Average	22	22	22	36	34	12	13
CHD	Maximum	43	27	26	40	42	18	16

[1]Insufficient data to compute average DAR.

Table 12. Summary of average and maximum values of derived angle of rotation (DAR) for kickback test series 2.

		DAR, deg						
Test Subject	Kickback Angle	G1	G2	G3	G4	G5	E6	E7
CDS	Average	23	29	30	42	50	17	16
CDS	Maximum	29	34	41	52	52	19	21
CR	Average	23	15	16	37	35	10	10
CR	Maximum	35	18	18	48	42	15	12
CJ	Average	31	15	15	32	37	13	13
CJ	Maximum	39	17	16	35	47	14	16
CHD	Average	25	26	23	41	42	19	21
CHD	Maximum	28	30	25	47	49	23	27
CN	Average	12	14	18	37	35	10	11
CN	Maximum	15	18	21	41	45	12	20
NB	Average	17	20	18	41	43	16	10
NB	Maximum	21	28	23	48	57	19	14
CD	Average	31	17	20	26	22	15	27
CD	Maximum	41	22	23	34	33	20	42

Table 13. Comparison of average and maximum values of derived angles of rotation for Kickback Test Series 1, Series 2, and combined test series with energy determined in Kickback Machine (KBM)[1].

Test Saw	Test Series 1		Test Series 2		Combined Test Series		Total Energy joule (in-lbf)		Rotational Energy joule (in-lbf)	
	Avg. DAR (deg)	Max. DAR (deg)	Avg. DAR (deg)	Max. DAR (deg)	Avg. DAR (deg)	Max. DAR[2] (deg)				
G1	15	23	23	30	18	26	12.6	(112)	9.5	(84)
G2	20	25	19	24	20	25	13.6	(120)	11.1	(98)
G3	17	22	20	24	18	22	10.7	(95)	9.7	(86)
G4	33	39	36	44	34	41	36.3	(321)	32.5	(288)
G5	29	36	38	46	32	40	51.8	(458)	46.7	(413)
E6	14	17	14	17	14	17	9.6	(85)	8.6	(76)
E7	16	24	15	22	16	23	11.9	(105)	7.6	(67)
Avg. Coef. of Variation	0.25		0.20		0.23					

[1] For Test Series 1 and 2, the DAR values are averages for 11 and 7 test subjects, respectively. For the combined test series, the DAR values are for 18 subjects (11 test subjects with replicate tests for 7 of these during Series 2).

[2] The maximum DAR values denote the mean of the largest derived angles of rotation for the respective test series.

6.3 Evaluation of Low Kickback Energy Chain

At the request of the CPSC, an extra set of hand-held kickback tests were conducted for three test subjects to evaluate a specially designed saw chain. In the last few years, several chain manufacturers have developed saw chains designed to reduce the kickback energy potential for some types of consumer chain saws. A series of kickback tests had been performed during earlier tests with the KBM in which one of these "low energy" chains was compared with a standard-type chain for test saw G5 [1].

A similar set of hand-held kickback tests were conducted using the low energy chain as well as the original equipment chain for saw G5. Since these two chains were identical to the chain used in the evaluation of kickback energy determined with the KBM, it was possible to compare the reduction in kickback for the low energy chain in terms of kickback derived angle of rotation as well as in terms of kickback energy. The results of kickback tests in the KBM and during the hand-held tests for the two chain designs are summarized in table 14.

Table 14. Comparison of kickback tests using original equipment (O) and low energy (L) chain for Saw G5.

Kickback Test	Average DAR, deg		Total Energy joule (in-lbf)		Reduction in Kickback,[1] percent
	Chain O	Chain L	Chain O	Chain L	
Hand-held (Subject CDS)	50	11	–	–	78
(Subject CR)	35	5	–	–	86
(Subject CJ)	37	7	–	–	81
Kickback Machine	–	–	53.0 (469)	14.9 (132)	72

[1] Percent Reduction in Kickback = $\dfrac{\text{Kickback for Chain O} - \text{Kickback for Chain L}}{\text{Kickback for Chain O}} \times 100$

6.4. Evaluation of Handle Spacing Effect on Saw Motion

Test Saw G1 was unique among the saws used in the hand-held kickback program in that it had two throttle trigger locations on the rear handle. The forwardmost trigger was located approximately 5 cm (2 in) from the saw front handle, and the rearmost trigger was located 16 cm (6.5 in) from the front handle, measured along a line parallel to the flat portion of the guidebar. Due to this trigger arrangement, it was possible to investigate the influence of handle spacing on the motion of Saw G1 during the hand-held kickback tests.

To facilitate an unbiased determination of the handle spacing effect, the replicate tests for Saw G1 were arranged so that some test subjects gripped only the front throttle trigger, some gripped only the rear trigger, and some subjects alternated the trigger they gripped for the replicate tests.[6] A summary of the derived angles of rotation for the Test Series 1 and 2 for Saw G1, using the two right-hand grip positions, are given in table 15. The throttle trigger gripped for each kickback test is noted in the table by the symbols F (forward throttle) and R (rear throttle). The average DAR when the subject gripped the rear throttle trigger was 17.6 deg; when the subject gripped the front throttle trigger, the average DAR was 19.5 deg. Although the differences in the average DAR for the two right-hand grip positions is not large, it is in the direction which was expected since the operator's hands are closer together when the front trigger is gripped.

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[6]The random match for the replicate tests was provided by the CPSC and is discussed in Appendix B.

Table 15. Derived angles of rotation for kickback tests with Saw G1 for two rear handle grip positions.

Test Series	Test Subject	Derived Angle of Rotation, deg				
		Test 1	Test 2	Test 3	Test 4	Test 5
1	CS	5(R)	3(R)	7(R)	1(R)	6(R)
	CK	7(R)	19(R)	16(R)	11(F)	7(F)
	CR	25(R)	24(R)	7(R)	10(R)	15(R)
	CN	16(F)	15(F)	10(F)	13(F)	10(F)
	CJ	9(R)	21(R)	11(R)	18(F)	13(F)
	CD	16(F)	13(F)	17(F)	11(R)	8(R)
	CMJ	19(F)	16(F)	15(F)	19(R)	15(R)
	CA	44(R)	[1]	[1]	[1]	29(F)
	NB	14(R)	16(R)	12(R)	10(R)	11(R)
	CDS	26(F)	27(F)	30(F)	[1]	26(F)
	CHD	43(F)	18(F)	19(F)	16(F)	13(F)
2	CDS	24(F)	29(F)	17(F)	27(F)	20(F)
	CR	22(F)	15(F)	35(R)	25(R)	18(R)
	CJ	27(F)	35(F)	25(F)	39(F)	27(F)
	CHD	26(R)	28(R)	23(R)	24(R)	25(R)
	CN	9(F)	10(F)	14(F)	15(F)	10(F)
	NB	17(R)	21(R)	13(R)	18(R)	16(R)
	CD	41(R)	23(R)	25(R)	34(R)	[1]

(F) - Subject gripped front throttle trigger.

(R) - Subject gripped rear throttle trigger.

[1]Malfunction of recording system occurred during test.

7. Discussion

The preceding sections of this report describe 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. The parameter selected to characterize the saw motion was the derived or apparent angle of rotation as defined from in-depth investigation analyses of chain saw accidents by the CPSC. For each of the test subjects, significant differences were found in both average and maximum angles of rotation among the sample of saws which they held during simulated kickback.

A computer-controlled optoelectronic system employed for measuring the displacements in real time, at selected locations on the test saws, was required to determine the saw positions throughout a simulated kickback. The computer analyses of the large amount of displacement-time data required to define the path of a chain saw during kickback demonstrated several advantages of this measurement system compared to high-speed cinematography. Visual analyses for the latter are both time-consuming and suceptible to human error.[7] The analyses of digitized data with a computer obviate the need for visual procedures to define the saw position over small time increments which characterize a kickback event. Furthermore, since the coordinate-time data are measured in digital form, additional kinematic parameters are easily computed. An example of this feature is given in Appendix C, in which the chain saw rotations for two test subjects were computed using three different reference systems. Such analyses permit a more thorough assessment to be made of the potential hazards to a chain saw operator in the absence of quantitative kickback data in a "field" situation.

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[7]Reference [5] provides an additional critique of film techniques to collect kinematic data.

A coefficient of variation for the computed angles of kickback rotation, i.e., the standard deviation divided by the mean value for five replicate tests, was chosen as an index of the test variability. For Test Series 1 and 2, the overall coefficient of variation for all test subjects and saws was 0.25 and 0.20, respectively. This result is comparable to the same measure of repeatability characteristic of the kickback data obtained with the KBM, particularly when the orders of magnitude for the rotation angle and the kickback energy are compared [1].

Analyses of the hand-held kickback data clearly indicate that the test arrangement and procedures for the experimental program resulted in saw motion data which were both repeatable and discriminating. Thus, it is possible to compare the derived angles of rotation with the energy data, which is required for CPSC injury reduction studies [3]. The large reduction in the derived angle of rotation for Saw G5 when equipped with a low kickback energy chain, compared to the original equipment chain, tends to confirm the known reduction in kickback energy for the same saw and chain combinations when evaluated in the KBM using the corresponding test parameters. In a special investigation for Saw G1 it was found that the effect of handle spacing on the saw kickback motion was not large, but indicated that larger handle spacing tended to reduce the angle of rotation as would be expected based on consideration of mechanical principles.

Procedures for the simulation of hand-held kickbacks other than those used in this investigation might have achieved larger chain saw motion, but also might have posed greater risks to the volunteer operators and/or introduced greater test variability. In this regard, it should be noted that, during kickback tests for three operators who held either of two saws, the shielded guidebar struck the safety bar which limited the saw rotation--in some cases, with considerable impact force.[1]

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[1] The safety precautions developed for the experimental program were designed specifically for this type of contingency (see Appendix A).

Thus, the average and peak angles of rotation for these tests, which are noted in the report, represent conservative values. It can be expected that the additional test saw inertia due to use of the guidebar shields would also tend to reduce the saw motion compared to that encountered in a "field" situation during a kickback event.

8. Acknowledgments

The assistance of Messrs. J. Huckeba and H. Kratz in conducting the experimental program and construction of the test apparatus, respectively, is gratefully acknowledged. Dr. A. Dainis and Mr. D. Brenner provided valuable assistance in the operation of the optoelectronic measurement equipment and interfacing of the latter with a high-speed computer. Mr. H. Lucas of the Consumer Product Safety Commission provided useful information throughout the experimental program; Ms. V. Brown and Ms. L. Santelli of the CPSC provided valuable assistance in the human factors and data analysis aspects of the program, respectively. Dr. H. P. Van Cott, Bio- Technology, Inc., served as a human factors consultant; his recommendations for the experimental design are summarized in Appendix B.

9. References

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Appendix A.   Development of Test Protocol

Test Stand Arrangement

In order to develop the test protocol for conducting hand-held chain saw kickback tests, it was first necessary to fabricate a test stand to assist in controlling specific test parameters and test-subject variability. Since the hand-held kickback data were required to establish the relationship between the energy determined when using the Kickback Test Machine (KBM) and kickback angle, the test stand was arranged to simulate a kickback in the same manner as for the KBM [1].

For the hand-held tests, a volunteer operator held an operating chain saw so that the guidebar was aligned in a horizontal position. Detailed procedures required to accomplish this in a safe manner are described later. The method for initiating a kickback during hand-held tests was identical to the procedure developed for the KBM; i.e., a fiberboard test specimen, clamped to a carriage assembly, was brought into contact with the moving chain at the upper quadrant of the test saw guidebar nose. The principal change in the hand-held test arrangement was the necessity for covering the straight portion of the guidebar with a shield to protect the saw operator. The shields were made as light in weight as possible to minimize their inertia. The carriage horizontal motion was controlled by a pair of horizontal rails to which the carriage was attached by four low-friction linear bearings. The carriage, which weighed 6.08 kg (13.40lbm), was accelerated by a weight falling inside a vertically mounted tube; the carriage assembly is shown in figure A.1.
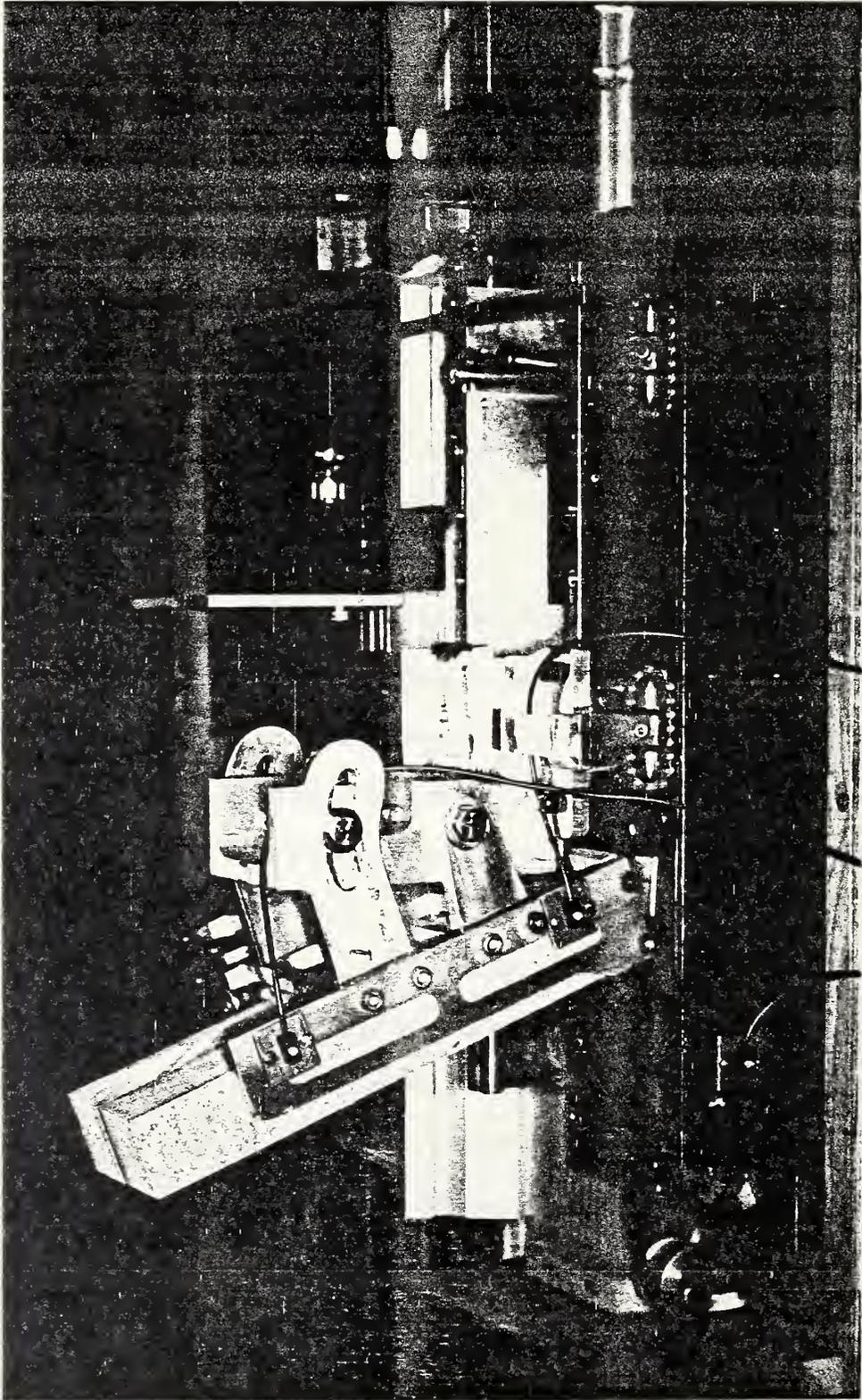
Figure A.1. Test Fixture Carriage Assembly

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Protocol for Initiation of Chain Saw Kickback

In the Kickback Test Machine, a kickback is initiated by guiding a low friction carriage, holding a fiberboard specimen, along a guiderail into the upper nose quadrant of a clamped chain saw. The guidebar of the test saw is aligned in a horizontal position and the saw is free to rotate about its center of gravity following contact of the wood specimen with the guidebar. The carriage design features in this arrangement include: 1) acceleration of the carriage by means of a falling weight to achieve the desired approach speed, after which the weight is bottomed to permit the carriage to maintain the desired speed just prior to contact of the wood specimen with the saw guidebar; 2) an adjustable clamping assembly to permit the wood specimen angle to be adjusted relative to the initial horizontal position of the test saw guidebar; and 3) provision for the addition of weights so that the carriage weight can be adjusted (the latter is a requirement in the test protocol for the KBM).

In the test arrangement for the hand-held kickbacks, all of the principal features of the KBM carriage were reproduced in order to enable the results of the hand-held kickbacks to be correlated with data obtained with the KBM without introducing additional test carriage variables. In lieu of the instrumentation for the KBM, a photocell device was used to record the approach velocity of the carriage, which is an important test parameter.

Rationale for Kickback Initiation Procedure

The procedure for initiating kickback in the KBM requires that the wood test specimen be guided at a preselected constant velocity into the upper nose quadrant of a motionless chain saw. The saw is positioned so its guidebar is horizontal and precautions are taken in the test procedures for the KBM to closely control: 1) the initial horizontal position of the saw, 2) the contact angle, and 3) the approach velocity of the wood specimen. Initiation of

a kickback during hand-held tests was achieved in the same manner so as to permit close control of the latter test parameters, which fundamentally influence the experimental initial and boundary conditions.

Furthermore, it was found from exploratory hand-held tests in which kickback was initiated by moving a saw guidebar toward a fixed wood specimen that the approach speed and initial saw position are more difficult to control if the saw guidebar is not supported. Alternatively, if a saw was supported on a level device which in turn is guided at a preset speed into a fixed wood specimen, then the time-dependent operator forces required to keep the moving saw in the proper alignment introduced other sources of test variability.

Additional Test Procedures

In addition to the procedures associated with the kickback initiation, several other test procedures were required due to the use of volunteer chain saw operators. As has been indicated, the kickback initiation procedure used in the experimental program required that a test subject assume a passive mode. This mode simulated a bucking operation, with the guidebar partially supported as if a chain saw were cutting through a horizontally positioned limb. Based on data from the CPSC accident investigations, a guidebar support length of approximately 18 cm (7 in) was chosen. The test saw guidebar was held in a horizontal position by resting the guidebar safety shield on a wooden block. The thumb of the operator's left hand was hooked below the saw front handle, and the operator stood so that his/her body was to the side of the cutting plane (plane of chain rotation passing through the saw guidebar). For the additional safety of the operator, a wood barrier was placed in front of the operator to prevent excessive rotational saw motion. The primary consideration with regard to upper torso position was the comfort of the test subject.

The rear handle of a chain saw typically has incorporarated into it the throttle control trigger. This trigger is usually a lever or switch activated by the operator's right index finger as his/her right hand grips the rear handle. It was necessary that all the test subjects keep a firm grip on the rear handle of the test saws. The requirement for squeezing the throttle control trigger to control the preset engine speed for a gasoline saw or activate an electric-powered saw tended to insure that the rear handle was properly gripped.

When the operator held the front handle of a test saw there were two specific requirements: 1) the fingers of the left hand were wrapped around the handle such that the handle diameter was kept in the webbing between the subject's thumb and index finger, and 2) the left hand was positioned on the handle such that it was approximately adjacent to the top end of the handle; i.e., the end of the handle closest to the cutting plane of the guidebar. The first of these requirements insured that the operator had the saw under control, whereas the second requirement was intended to minimize out-of-plane kickback motion of the test saw.

The test subjects were allowed to experience low energy kickbacks after the gripping and stance modes were explained and demonstrated by the principal investigator. For both the safety of the operators and the uniformity of the test results, the initial subject body position and method of gripping the test saws was maintained throughout the experimental program. Detailed discussions of the various human factors aspects of the program are given in Appendix B.

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Appendix B. Human Factors Recommendations and Rationale for Testing Chain Saw
Kickback with Volunteer Operators.

Introduction

The Consumer Product Safety Commission (CPSC) funded the National Bureau
of Standards (NBS) to develop and implement a test protocol and test proce-
dures in order to obtain kickback data on chain saws operated by volunteer
operators. NBS obtained the services of Bio Technology, Inc., to provide
human factors recommendations for the test. This appendix presents Bio Tech-
nology's human factors recommendations and rationales for the kickback experi-
mental program.

Purpose

In support of chain saw standard development, NBS performed a study to
measure the magnitude and relative difference in the kickback of different
chain saws operated by individuals under conditions simulating consumer chain
saw use. The objective of the study was not to measure human performance but
rather to measure kickback performance of saw-person combinations.

Representatives and Realism

Insofar as possible the test protocol and procedures approximated the
conditions of real-world saw use but in an environment that protected volun-
teer subjects from injury and that permited adequate experimental control to
be exercised in taking kickback measurements. This required some compromise
between safety and the generality of results to real-world saw use.

Subject Characteristics

Ideally, subjects to be employed in the test should be statistically representative of the population of chain saw users. However, the user population characteristics were not known so the subpopulation of injured saw users as defined by the National Electronic Injury Surveillance System (NEISS) data were used to identify subject characteristics. Subject variables judged to be of importance in subject selection included: sex, age, weight, height, handedness (if this appears as a discriminating variable in the NEISS data) and chain saw use. Other subject variables, such as socio-economic status or educational achievement were not judged to be important variables in determining saw-user behavior.

Sample Size and Selection

Volunteers from NBS and the Consumer Product Safety Commission were used with full recognition that volunteers drawn from either organization may have special knowledge or attitudes on risk and safety which would limit the generality of findings to the injured population at large. The subject profiles are attached to the end of this appendix (table B-2).

Subject Safety Vs. Realism

To the maximum extent possible, the conditions (modified to insure subject safety) of saw use in the test were representative of the conditions of real-world use. All subjects were required to wear hearing protectors to guard against the possibility of hearing loss, though such loss was not likely in the brief periods of exposure to the testing situation.

The test saws were held by subjects in a test arrangement that did not interfere with saw operation or attenuate saw kickback. Subjects were

protected from facial injury by a transparent barrier, rather than a helmet, which did not restrict the size of the visual field or encumber subject movement. A shield covering the flat portion of the guidebar was employed to protect against injury to the limbs and torso without constraining the subject and without requiring an unnatural stance or grip of the saw during saw use. A floor covering was employed in order to reduce the possibility of slips and falls. Ambient lighting in the test environment was adequate for subjects to see and operate the saw and test samples.

The test environment was free from extraneous noise and distractions that would interfere with or stress subject performance or degrade oral communication between subjects and test personnel.

Subject Treatment

Prior to testing (at least one day in advance) all test subjects were given and required to read and understand saw safety guidelines provided by the CPSC. Subject release forms required subjects to attest to having read the CPSC safety guidelines prior to testing.

Prior to testing, each subject completed a questionnaire requesting information on the subject's sex, age, height, weight, and previous saw use experience. Other variables, such as corrected vision or occupation, were included in the questionnaire, but these variables are unlikely to be important sources of variance in subject performance.

All subjects were given the same oral instructions prior to testing. Standardization was insured by having the same test supervisor read the instructions to all the subjects. Instructions described what the subject was to do and how it was to be done. It was neither necessary nor desirable that the subject be informed of the purpose of the study since such knowledge might bias performance.

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All saws were tested by each subject. In order to account for the effects of subject learning (i.e., experience) on saw kickback, the order in which saws were presented was randomized across and within subjects as shown in table B-1. Over half of the subjects tested were retested to determine if there were any differences between the first and second trial of saw use.

Subject Tension/Relaxation

Since the subject-saw combination is a mechanical linkage having unknown stiffness and damping characteristics, some estimate of the degree of tension or relaxation of the subject is desirable. Although myographic measures of muscle tension or other physiological measures could have been taken, their correlation with a subject's state of relaxation or tension is known not to be high. A somewhat better measure is self-perceived tension/relaxation. Each subject was asked to estimate his/her degree of relaxation or tension on a scale from 1 (very relaxed) to 5 (very tense) after each measurement trial. While this is a less than perfect tension measure, data from such ratings may partially account for between-subject differences in saw kickback.[8]

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[8]These ratings were recorded and evaluated by the CPSC for the kickback experimental program. The evaluation forms were analyzed by the CPSC Division of Human Factors.

Table B-1. Chain saw hand-held test random match of subjects and saws.

| | | | Saw Gl Trigger Match[2] | | |
Subject	Saw Order[1]	Test Series	Trigger Used	Times Rear Trigger was Used	First Trigger Used
1	6,1,3,2,4,5,7	1	Rear	5	Rear
2	6,7,5,4,1,2,3		Both	3	Rear
3	6,4,1,3,5,2,7		Rear	5	Rear
4	6,4,5,2,7,3,1		Front	0	Front
5	6,4,5,2,1,3,7		Both	3	Rear
6	6,7,3,4,1,2,5		Both	2	Front
7	6,5,7,1,2,4,3		Both	2	Front
8	6,4,2,3,5,1,7		Both	2	Rear
9	6,4,3,5,7,1,2		Rear	5	Rear
10	6,3,1,5,7,2,4		Front	0	Front
11	6,1,7,5,2,4,3		Front	0	Front
10	6,2,5,3,1,7,4	2	Front	0	Front
3	6,3,1,4,2,5,7		Front	0	Front
5	6,5,3,2,7,1,4		Rear	5	Rear
11	6,4,1,5,7,3,2		Both	3	Front
4	6,7,2,5,4,1,3		Rear	5	Rear
9	6,4,1,7,5,2,3		Front	0	Front
6	6,5,7,1,4,2,3		Rear	5	Rear

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[1]Random matches were provided by the Consumer Product Safety Commission. Saw E6 was presented first to each subject for training purposes, since it was a saw having relatively small kickback characteristics based on prior tests with the Kickback Test Machine.

[2]Saw Gl was the only test saw having two throttle triggers, both located on the rear handle.

Test Subject Evaluation

The following evaluation sheet was prepared by the CPSC as another means

of subject evaluation to supplement the measurements of saw kickback motion.

TEST SUBJECT EVALUATION SHEET

Name: _____ Date _____

Instructions: After completion of each trial, please indicate, by circling one number on the scale of from 1 to 5 that value which best describes your state of muscle relaxation during that trial.

1 2 3 4 - 5

Very Relaxed ———————————— Very Tense

SAW	TRIAL	RATING	SAW	TRIAL	RATING
	Saw I D Provided			Saw I D Provided	
1	A	1 2 3 4 5	6	A	1 2 3 4 5
	B	1 2 3 4 5		B	1 2 3 4 5
	C	1 2 3 4 5		C	1 2 3 4 5
	D	1 2 3 4 5		D	1 2 3 4 5
	E	1 2 3 4 5		E	1 2 3 4 5
2	A	1 2 3 4 5	7	A	1 2 3 4 5
	B	1 2 3 4 5		B	1 2 3 4 5
	C	1 2 3 4 5		C	1 2 3 4 5
	D	1 2 3 4 5		D	1 2 3 4 5
	E	1 2 3 4 5		E	1 2 3 4 5
3	A	1 2 3 4 5	8	A	1 2 3 4 5
	B	1 2 3 4 5		B	1 2 3 4 5
	C	1 2 3 4 5		C	1 2 3 4 5
	D	1 2 3 4 5		D	1 2 3 4 5
	E	1 2 3 4 5		E	1 2 3 4 5
4	A	1 2 3 4 5	9	A	1 2 3 4 5
	B	1 2 3 4 5		B	1 2 3 4 5
	C	1 2 3 4 5		C	1 2 3 4 5
	D	1 2 3 4 5		D	1 2 3 4 5
	E	1 2 3 4 5		E	1 2 3 4 5
5	A	1 2 3 4 5	10	A	1 2 3 4 5
	B	1 2 3 4 5		B	1 2 3 4 5
	C	1 2 3 4 5		C	1 2 3 4 5
	D	1 2 3 4 5		D	1 2 3 4 5
	E	1 2 3 4 5		E	1 2 3 4 5

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Table B-2. Test subject profiles

Subject	Sex	Age (years)	Height (in)	Weight (lbs)	Handed	Chain Saw Use
CR	M	55	65	154	R	Yes
CHD	M	40	71	176	R	Yes
NB	M	44	59	160	R	Yes
CN	F	54	63	128	R	Yes
CJ	M	43	65	158	R	Yes
CD	M	33	69	184	R	Yes
CMJ	M	31	76	197	R	Yes
CDS	F	25	65	112	R	No
CA	M	43	67	198	R	Yes
CK	M	33	67	174	L	No
CS	M	42	75	286	R	Yes

Appendix C. Computer Analysis of Recorded Data.

A high-speed computer was utilized to perform necessary corrections and transformations of the digitized saw displacement data recorded by the opto-electronic measurement system. This analysis included corrections for lens curvature of the recording camera and for the desired diode positions to facilitate interpretation of the saw motion relative to the body of a chain saw operator. Transformations of the data to a coordinate system at the saw center of gravity when the kickback was initiated (time = 0), and conversion of the displacements from the measurement system units to inches were also performed.

Furthermore, it was required that the saw rotational motion during a kickback be defined relative to three saw references: 1) the moving center of gravity of the saw, 2) a fixed reference at the rearmost position of the saw as the kickback was initiated (CPSC definition of the derived rotation angle), and 3) a fixed reference at the rear handle throttle trigger at the kickback initiation (CSMA definition of the derived rotation angle). The equations for these corrections and transformations of the recorded data are given in the following sections of this appendix.

Correction for Recording Camera Lens Curvature

A program was written for calculating the change in the diode coordinates, due to distortion in Selspot camera system, using a look-up table. The program corrects for the discrepancies between the known calibration points in the object space and the optically produced position of these points.

A grid of 1024 by 1024 coordinate components used by the Selspot electronics (a direct result of a 10-bit word address) is divided up into 289 x-components and 289 y-components which are each represented by a 17 by 17

matrix or look-up table. For the program printed at the end of this appendix, the x and y look-up tables are given in tenths of millimeters. Conversion from millimeters to inches is performed after an interpolation process is completed.

Under controlled laboratory conditions, the true grid (1600 mm by 1600 mm) was measured by the Selspot System, as shown in figure C-1. Subsequently, corrected look-up tables were generated to account for the change in coordinates due to lens distortions. By incorporating these corrected look-up tables, a simple interpolation routine was then used to find the corrected coordinates from those recorded by the Selspot System during the kickback tests. One critical factor that had to be taken into account in the above analysis was the camera-to-object distance. This factor was entered as a constant related to the camera-to-grid distance used in the initial calibration of the Selspot System.

Conversion of Diode Positions and Computation of CPSC Kickback Angles

Throughout the experimental program, the positions of the saw tip, center of gravity, and rear handle were defined by the coordinates $(X3,Y3)$, $(X4,Y4)$, and $(X5,Y5)$, respectively. In general, the diodes were placed adjacent to, but not exactly at the desired saw positions. The parameters used to relate the test coordinates and these desired positions for the diodes at the saw tip, center of gravity, and rear handle were $(A1,A2)$, $(C1,C2)$, and $(R1,R2)$, respectively, when the saw was in its original position at the inception of kickback, i.e., at time $t = 0$. Table C-1 summarizes the saw parameters required for these computations. At the time chosen as $t = 0$, the following constants define the saw initial position:
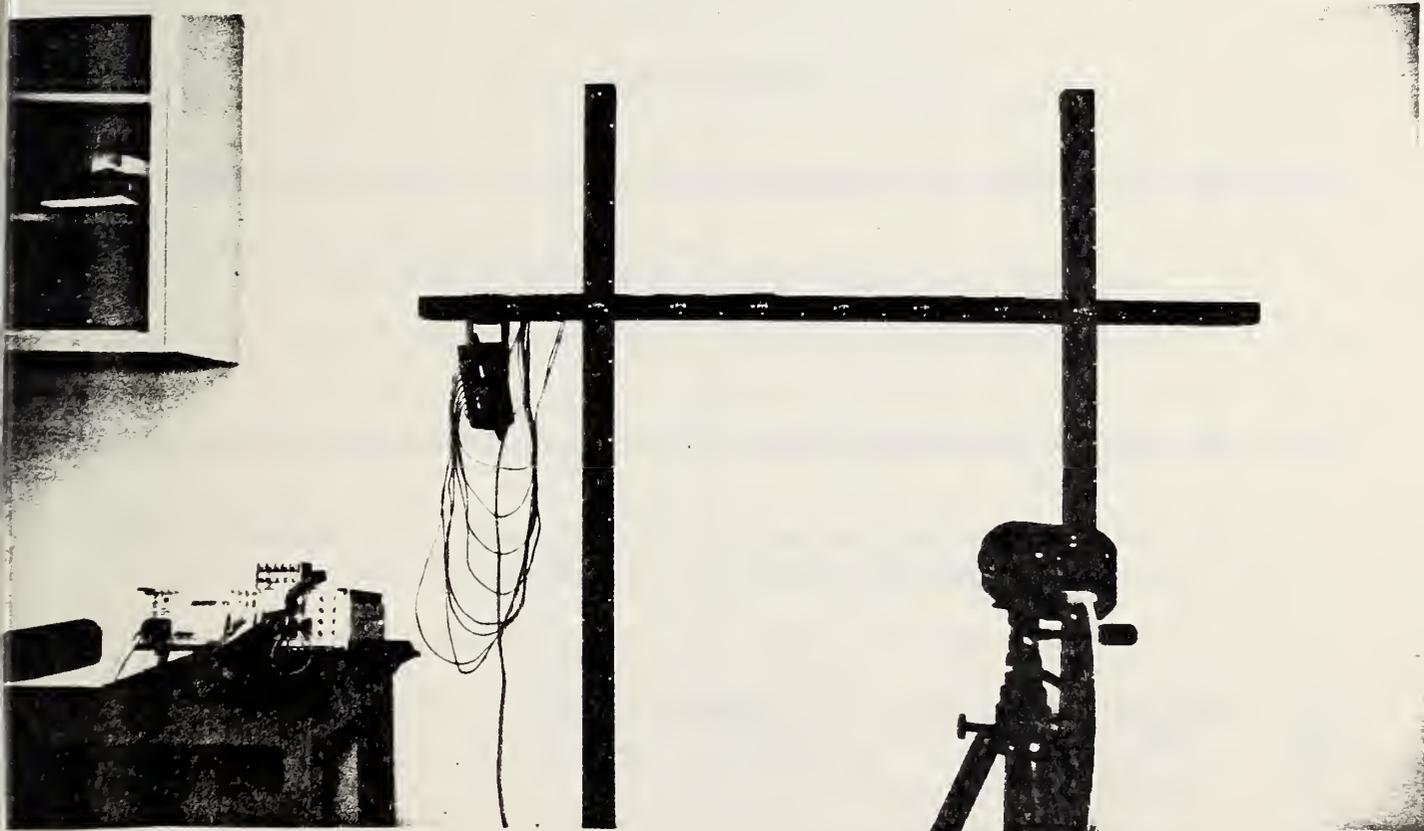
Figure C.1.   Arrangement of Optoelectronic Camera and Calibration Grid
(instrumented bar moved to various elevations)

$$VO = Y3 \qquad (C.1)$$

$$HO = X3 \qquad (C.2)$$

$$YO = Y4 \qquad (C.3)$$

$$XO = X4 \qquad (C.4)$$

At the inception of kickback (t = 0), let

$$S1 = X5 + R1 \qquad (C.5)$$

$$S2 = Y5 + R2 \qquad (C.6)$$

$$Q1 = XO + C1 \qquad (C.7)$$

$$Q2 = YO + C2 \qquad (C.8)$$

The rotation of the saw about its center of gravity is then defined as

$$A = \tan^{-1}[(Y3-Y4)/(X3-X4)] - \tan^{-1}[(VO-YO)/(HO-XO)] \qquad (C.9)$$

where A is an angle in degrees for all times during the kickback event.

Table C-1. Saw paremeters used to correct diode test coordinates
to desired positions.

Test Saw	Tip Correction (in)		C.G. Correction (in)		Rear Handle correction (in)	
	A1	A2	C1	C2	R1	R2
G1	− 1.00	− 0.44	0	0	− 2.12	+ 0.69
G2	− 1.31	+ 1.06	+ 0.06	0	− 1.56	− 1.31
G3	− 1.31	+ 0.88	− 0.38	+ 0.88	− 2.62	+ 0.50
G4	− 0.75	+ 1.12	0.0	− 0.75	− 2.56	+ 1.62
G5	− 1.69	+ 0.34	+ 0.16	+ 0.06	+ 0.12	− 0.03
E6	− 1.25	0	+ 0.62	+ 0.50	− 2.44	− 0.12
E7	− 1.75	+ 0.81	+ 0.19	+ 0.19	− 0.50	+ 0.19

The corrected positions for the diode positions at the saw tip, center of gravity, and rear handle are defined as (T1, T2), (G1, G2), and (H1, H2), respectively, and are computed as follows:

$$T1 = X3 + A1 \cos A - A2 \sin A \tag{C.10}$$

$$T2 = Y3 + A1 \sin A + A2 \cos A \tag{C.11}$$

$$G1 = X4 + C1 \cos A - C2 \sin A \tag{C.12}$$

$$G2 = Y4 + C1 \sin A + C2 \cos A \tag{C.13}$$

$$H1 = X5 + R1 \cos A - R2 \sin A \tag{C.14}$$

$$H2 = Y5 + R1 \sin A + R2 \cos A \tag{C.15}$$

The derived angle of rotation (DAR) relative to a fixed position at the rear of the saw is computed as follows:

$$D = \tan^{-1} [(T2-S2)/(T1-S1)] - \tan^{-1} [(V0+A2-S2)/(H0+A1-S1)] \tag{C.16}$$

where D is the angle in degrees for all times during the kickback (CPSC definition of DAR).

To convert the displacement data to the coordinate system whose origin is at the saw center of gravity as it moves, the following transformations are used:

$$T1 = T1 - Q1 \tag{C.17}$$

$$T2 = T2 - Q2 \tag{C.18}$$

$$G1 = G1 - Q1 \tag{C.19}$$

$$G2 = G2 - Q2 \tag{C.20}$$

$$H1 = H1 - Q1 \tag{C.21}$$

$$H2 = H2 - Q2 \tag{C.22}$$

where (T1,T2), (G1,G2), and (H1,H2) define the (X,Y) coordinates at the saw tip, center of gravity, and rear handle, respectively, for all times during the kickback.

Computation of CSMA Derived Angle of Rotation

In order to compute the derived angle of rotation in terms of the CSMA reference system, it is necessary to use additional saw parameters. These parameters define the (X,Y) coordinates of the rear handle throttle trigger at the kickback initiation and locate the guidebar tip coordinates somewhat differently than for the CPSC reference system. The parameters (L3,L4) and (A3,A4) define the trigger and tip coordinates, respectively, and are summarized for the various test saws in table C-2.

Table C-2. Saw parameters used to compute CSMA derived angle of rotation.

| Test Saw | Saw Dimensions (in) | | | |
	L3	L4	A3	A4
G1	+ 6.06[1]	+ 2.44[1]	− 1.12	− 0.93
G2	+ 4.06	+ 3.00	− 1.06	− 0.93
G3	+ 3.75	+ 2.31	− 0.87	− 0.94
G4	+ 9.00	+ 1.25	− 1.13	− 1.12
G5	+ 8.69	+ 0.62	− 1.13	− 1.07
E6	0[2]	0	0	0
E7	+ 6.06	+ 0.94	− 0.75	− 0.69

[1]Dimensions for L3 and L4 were based on measurements at the rear trigger location for test saw G1.

[2]Saw dimensions not measured for test saw E6. Values of zero were used to implement running of the computer program.

Using the definitions for T1, T2, A, Q1, and Q2, as defined in eqs. (C.7) through (C.11), the following expressions are computed at each time:

$$T3 = T1 + A3 \cos A - A4 \sin A - Q1 \qquad (C.23)$$

$$T4 = T2 + A3 \sin A + A4 \cos A - Q2 \qquad (C.24)$$

The CSMA derived angle of rotation (DAR) relative to a fixed position at the throttle trigger is computed as follows:

$$B = \tan^{-1} [(T4-L4)/(T3-L3)] \qquad (C.25)$$

where B is the DAR in degrees for all times during the kickback.

Computer Analysis

Equations for the corrections and the transformations which have been discussed were programmed for a mini-computer to analyze the recorded kickback displacement data; the software for this analysis is given at the end of the appendix. Examples of the corrected values for the CPSC and CSMA derived angles of rotation for Test Subjects CDS and NB are given in tables C-3 and C-4, respectively.

Corrections due to distortion in the recording camera system were found to change the computed angles of rotation by approximately one degree or less, based on comparison of corrected and uncorrected displacement data. Corrections due to the diode positions generally modified the computed angles of rotation by two degrees or less.

In order to facilitate the interpretation of the saw rotational motion during the kickback tests, the maximum rotation angles about the saw center of gravity were determined for Test Subjects CDS and NB and are presented in tables C-5 and C-6, respectively. The time intervals from the first contact of the saw and wood specimen to the point of maximum rotation about the moving

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saw center of gravity are also shown; these values were less than or equal to the times required for the saws to reach the maximum values for the derived angles of rotation shown in tables C-5 and C-6. A sample of the computer analysis is given following table C-6.

Table C-3. Corrected values of kickback derived angles of rotation (DAR) for subject CDS.

Test Ser.	Test Saw	(DAR)$_{CPSC}$ for Replicate Tests (deg) [(DAR)$_{CSMA}$ for Replicate Tests (deg)]					Average DAR, deg	Std. Dev.	Coef. of Variation
1	G1	26.6 [22.3]	28.4 [24.7]	31.0 [27.6]	[1] [1]	26.7 [22.5]	28.2	2.06	0.07
	G2	40.8 [42.4]	23.8 [20.2]	30.4 [28.3]	32.8 [32.3]	28.5 [26.9]	31.3	6.27	0.20
	G3	22.1 [18.9]	18.5 [14.6]	24.5 [26.3]	31.2 [30.3]	33.6 [33.8]	26.0	6.29	0.24
	G4	54.4[2] [54.5]	51.1 [51.7]	37.7 [38.4]	38.7 [39.1]	53.5 [54.8]	47.1	8.20	0.17
	G5	49.9 [51.2]	32.9 [33.6]	52.9[2] [53.8]	51.1[2] [52.4]	48.9 [49.0]	47.1	8.10	0.17
	E7	15.7 [14.3]	15.2 [13.6]	19.9 [18.7]	14.0 [12.4]	32.9 [34.5]	19.5	7.79	0.40
2	G1	[1] [1]	27.7 [21.9]	16.6 [9.2]	26.2 [20.3]	19.3 [12.8]	22.4	5.35	0.24
	G2	34.5 [33.5]	33.2 [31.1]	[1] [1]	26.0 [19.3]	36.4 [34.7]	32.5	4.54	0.14
	G3	33.3 [32.4]	42.9 [46.9]	27.9 [26.7]	28.6 [27.3]	27.5 [26.1]	32.0	6.50	0.20
	G4	53.1[2] [53.7]	54.6[2] [54.5]	31.2 [30.3]	36.8 [36.0]	44.8 [44.2]	44.1	10.14	0.23
	G5	50.3[2] [50.7]	50.5[2] [52.1]	53.0[2] [53.9]	53.5[2] [54.4]	47.4 [47.9]	50.9	2.45	0.05
	E7	12.6 [10.2]	21.8 [21.7]	22.2 [21.2]	12.4 [9.6]	18.0 [15.8]	17.4	4.76	0.27

[1]Malfunction of recording system occurred during the test, interrupting data transfer to computer memory.

[2]Saw struck safety bar.

NOTE: for test saw G1, (DAR)$_{CSMA}$ was based on the rear trigger location.

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Table C-4. Corrected values of kickback derived angles of rotation (DAR) for subject NB.

Test Ser.	Test Saw	$(DAR)_{CPSC}$ for Replicate Tests (deg) $[(DAR)_{CSMA}$ for Replicate Tests (deg)]					Average DAR,deg	Std. Dev.	Coef. of Variation
1	G1	13.1 [8.2]	15.5 [8.4]	11.5 [9.0]	9.5 [8.6]	11.3 [9.1]	12.2	2.25	0.18
	G2	12.8 [6.6]	17.2 [12.2]	15.5 [9.5]	16.6 [10.4]	15.4 [8.9]	15.5	1.69	0.11
	G3	11.4 [4.9]	9.1 [9.5]	12.1 [5.9]	15.3 [10.3]	12.0 [5.8]	12.0	2.22	0.18
	G4	41.0[2] [40.6]	39.3 [39.1]	46.0 [45.4]	43.1 [42.7]	32.7 [31.7]	40.4	4.99	0.12
	G5	22.4 [21.6]	51.9[2] [51.4]	43.2 [42.3]	36.0 [35.2]	22.7 [21.6]	35.2	12.88	0.36
	E7	19.7 [18.1]	33.4 [34.8]	25.4 [24.8]	9.8 [5.8]	11.4 [8.4]	19.9	9.83	0.49
2	G1	15.5 5.9	20.9 [13.8]	12.9 [5.1]	[1] [1]	15.9 [7.6]	16.3	3.34	0.20
	G2	26.4 [19.9]	16.6 [10.9]	32.0 [28.5]	18.9 [11.6]	17.0 [9.2]	22.2	6.76	0.30
	G3	22.2 [18.5]	24.7 [22.6]	17.5 [12.2]	18.4 [13.5]	13.3 [7.2]	19.2	4.40	0.23
	G4	50.3 [49.8]	47.6 [46.8]	35.6 [34.3]	43.3 [42.4]	36.6 [35.3]	42.7	6.51	0.15
	G5	52.8 [53.9]	58.8 [60.5]	33.2 [33.0]	45.2 [46.2]	28.9 [28.9]	43.8	12.67	0.29
	E7	7.0 [4.2]	9.1 [6.8]	10.3 [8.2]	14.8 [12.7]	10.4 [8.2]	10.3	2.85	0.28

[1]Malfunction of recording system occurred during the test, interrupting data transfer to computer memory.

[2]Saw struck safety bar.

NOTE: for test saw G1, $(DAR)_{CSMA}$ was based on the rear trigger location.

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Table C-5. Maximum angles of kickback rotation about saw center of gravity for subject CDS.

Test Series	Test Saw	Maximum Rotation about Saw C.G., deg (Duration from Saw-Wood Contact, sec)					Average Duration, sec.
1	G1	23.2 (0.413)	25.4 (0.446)	29.2 (0.401)	[1] [1]	27.8 (0.433)	0.423
	G2	38.3 (0.099)	26.7 (0.086)	33.0 (0.093)	37.3 (0.086)	32.7 (0.086)	0.090
	G3	26.4 (0.080)	24.3 (0.080)	29.4 (0.093)	28.0 (0.086)	36.8 (0.093)	0.086
	G4	47.0 (0.231)	44.2 (0.196)	38.0 (0.109)	39.5 (0.112)	48.8 (0.218)	0.173
	G5	50.3 (0.099)	36.2 (0.096)	59.9 (0.090)	57.6 (0.099)	46.9 (0.102)	0.097
	E7	18.4 (0.064)	17.5 (0.067)	21.9 (0.093)	19.3 (0.080)	29.9 (0.096)	0.080
2	G1	[1] [1]	22.0 (0.423)	20.3 (0.118)	26.1 (0.125)	20.6 (0.458)	0.281
	G2	35.6 (0.096)	33.3 (0.096)	[1] [1]	22.9 (0.071)	28.2 (0.080)	0.086
	G3	30.4 (0.093)	38.7 (0.115)	32.8 (0.096)	32.1 (0.093)	27.2 (0.096)	0.099
	G4	49.8 (0.147)	52.8 (0.125)	31.2 (0.093)	35.5 (0.109)	38.6 (0.471)	0.189
	G5	52.1 (0.112)	53.4 (0.106)	60.4 (0.093)	59.7 (0.090)	43.1 (0.106)	0.101
	E7	14.7 (0.064)	26.0 (0.096)	25.6 (0.090)	15.5 (0.077)	20.9 (0.077)	0.081

[1] Malfunction of recording system.

Table C-6. Maximum angles of kickback rotation about saw center of gravity for subject NB.

Test Series	Test Saw	Maximum Rotation about Saw C.G., deg (Duration from Saw-Wood Contact, sec)					Average Duration, sec
1	G1	13.3 (0.676)	13.9 (0.609)	11.1 (0.452)	8.0 (0.401)	10.7 (0.494)	0.526
	G2	14.4 (0.054)	19.2 (0.067)	17.4 (0.051)	17.7 (0.067)	16.5 (0.054)	0.059
	G3	14.1 (0.061)	12.9 (0.064)	15.0 (0.054)	19.5 (0.067)	10.7 (0.056)	0.062
	G4	37.8 (0.154)	39.1 (0.115)	41.4 (0.160)	40.2 (0.151)	33.3 (0.099)	0.136
	G5	24.7 (0.083)	47.7 (0.118)	39.0 (0.090)	36.3 (0.090)	25.2 (0.083)	0.093
	E7	16.9 (0.497)	25.7 (0.510)	22.4 (0.436)	11.9 (0.048)	14.0 (0.054)	0.309
2	G1	11.5 (0.474)	16.8 (0.381)	11.2 (0.064)	[1] [1]	12.4 (0.401)	0.330
	G2	18.8 (0.070)	19.0 (0.074)	19.4 (0.086)	16.6 (0.080)	12.9 (0.074)	0.077
	G3	25.4 (0.077)	30.1 (0.090)	19.8 (0.077)	20.6 (0.083)	15.6 (0.064)	0.078
	G4	44.5 (0.189)	38.9 (0.336)	31.2 (0.138)	38.0 (0.144)	34.4 (0.112)	0.184
	G5	43.8 (0.106)	43.4 (0.586)	29.9 (0.099)	34.1 (0.426)	32.4 (0.090)	0.261
	E7	10.1 (0.058)	13.0 (0.067)	14.3 (0.070)	13.2 (0.061)	13.5 (0.061)	0.063

[1] Malfunction of recording system.

Time (msec)	Tip X (in)	Tip Y (in)	CG X (in)	CG Y (in)	RH X (in)	RH Y (in)	CG Ang (des)	DAR CPSC (des)	DAR IND (des)
0.000	17.343	0.067	0.000	0.000	11.505	1.867	0.000	0.000	3.701
3.205	17.284	0.059	0.000	0.001	11.504	1.748	0.419	0.243	3.424
6.410	17.334	0.307	0.057	0.055	11.611	1.630	1.055	0.739	2.870
9.615	17.207	0.813	0.114	0.050	11.771	1.393	2.745	1.734	1.737
12.821	17.019	1.561	0.283	0.159	11.875	0.978	4.855	3.221	0.063
16.026	16.758	2.688	0.453	0.264	12.084	0.386	8.239	5.499	2.509
19.231	16.369	4.067	0.621	0.367	12.234	0.381	12.509	8.347	5.726
22.436	15.919	5.327	0.844	0.471	12.330	0.971	16.385	11.026	8.746
25.641	15.463	6.592	0.956	0.633	12.316	1.620	20.177	13.772	11.827
28.846	14.895	7.795	1.067	0.796	12.252	2.035	23.905	16.490	14.876
32.051	14.274	8.867	1.232	0.959	12.240	2.566	27.246	19.028	17.716
35.256	13.656	9.858	1.398	1.124	12.175	2.979	30.347	21.455	20.424
38.462	13.091	10.842	1.562	1.289	12.056	3.452	33.332	23.883	23.111
41.667	12.479	11.702	1.783	1.455	12.101	3.746	35.931	26.133	25.594
44.872	11.814	12.443	1.947	1.622	11.981	4.100	38.411	28.232	27.920
48.077	11.144	13.284	2.111	1.788	11.972	4.279	41.168	30.587	30.506
51.282	10.485	13.995	2.331	1.956	11.800	4.516	43.445	32.713	32.828
54.487	9.888	14.643	2.495	2.183	11.795	4.577	45.411	34.681	34.960
57.692	9.285	15.347	2.660	2.410	11.623	4.813	47.520	36.792	37.228
60.897	8.745	15.988	2.824	2.638	11.511	4.816	49.329	38.725	39.284
64.103	8.152	16.515	2.989	2.866•	11.397	4.936	51.013	40.528	41.210
67.308	7.605	17.047	3.098	3.036	11.339	4.938	52.861	42.296	43.092
70.513	7.005	17.578	3.262	3.265	11.282	4.940	54.588	44.162	45.063
73.718	6.527	18.102	3.483	3.495	11.171	4.942	55.824	45.834	46.790
76.923	6.056	18.455	3.701	3.667	11.169	4.942	56.826	47.202	48.215
80.128	5.637	18.920	3.865	3.898	11.112	4.944	57.933	48.687	49.728
83.333	5.158	19.331	4.028	4.072	11.166	4.827	59.201	50.180	51.269
86.539	4.754	19.622	4.248	4.306	11.059	4.712	59.804	51.355	52.463
89.744	4.639	19.849	4.358	4.483	11.227	4.478	59.899	51.917	53.000
92.949	4.536	20.071	4.525	4.778	11.286	4.302	59.602	52.450	53.487
96.154	4.480	20.184	4.580	4.896	11.454	4.067	59.594	52.723	53.745
99.359	4.548	20.345	4.692	5.074	11.514	3.833	59.077	52.853	53.814
102.564	4.568	20.393	4.859	5.252	11.683	3.598	58.346	52.892	53.806
105.769	4.702	20.438	4.971	5.431	11.795	3.421	57.447	52.723	53.576

Time (msec)	Tip X (in)	Tip Y (in)	CG X (in)	CG Y (in)	RH X (in)	RH Y (in)	CG Ans (des)	DAR CFSC (des)	DAR IND (des)
0.000	17.423	0.127	0.000	0.000	11.274	1.859	0.000	0.000	3.816
3.205	17.365	0.001	0.056	0.001	11.327	1.741	0.419	0.243	3.541
6.410	17.414	0.246	0.057	0.055	11.435	1.622	1.049	0.741	2.989
9.615	17.296	0.555	0.169	0.110	11.433	1.503	1.883	1.347	2.313
12.821	17.224	1.061	0.225	0.105	11.593	1.265	3.558	2.355	1.177
16.026	17.090	1.749	0.338	0.156	11.752	0.908	5.645	3.737	0.372
19.231	16.777	2.683	0.562	0.263	11.854	0.432	8.368	5.642	2.503
22.436	16.512	3.742	0.730	0.370	12.064	0.044	11.495	7.836	4.953
25.641	16.076	4.798	0.897	0.534	12.161	0.576	14.527	10.093	7.469
28.846	15.693	5.744	1.008	0.641	12.207	0.990	17.413	12.157	9.773
32.051	15.362	6.745	1.119	0.806	12.253	1.288	20.244	14.354	12.206
35.256	14.868	7.566	1.175	0.972	12.191	1.642	22.760	16.275	14.345
38.462	14.483	8.442	1.341	1.138	12.238	1.939	25.199	18.297	16.571
41.667	14.048	9.187	1.506	1.305	12.230	2.234	27.294	20.100	18.556
44.872	13.559	9.868	1.672	1.472	12.279	2.413	29.286	21.837	20.471
48.077	13.183	10.542	1.837	1.641	12.273	2.650	31.074	23.506	22.289
51.282	12.701	11.213	2.112	1.809	12.378	2.712	32.835	25.273	24.212
54.487	12.326	11.884	2.222	1.977	12.318	2.889	34.683	26.974	26.055
57.692	11.900	12.493	2.388	2.146	12.423	2.892	36.345	28.609	27.822
60.897	11.430	12.970	2.553	2.374	12.366	3.010	37.581	30.036	29.364
64.103	11.067	13.556	2.719	2.602*	12.418	2.954	38.901	31.594	31.018
67.308	10.644	14.090	2.829	2.771	12.414	3.073	40.464	33.122	32.659
70.513	10.287	14.614	2.939	3.058	12.413	3.016	41.573	34.567	34.180
73.718	9.932	15.024	3.105	3.230	12.357	3.017	42.563	35.790	35.475
76.923	9.637	15.430	3.216	3.460	12.410	2.960	43.392	36.941	36.678
80.128	9.395	15.891	3.382	3.631	12.464	2.903	44.253	38.131	37.906
83.333	9.053	16.235	3.603	3.862	12.463	2.845	44.787	39.229	39.044
86.539	8.818	16.580	3.769	4.038	12.572	2.729	45.336	40.189	40.028
89.744	8.591	16.864	3.881	4.332	12.628	2.612	45.572	41.025	40.876
92.949	8.355	17.264	4.047	4.567	12.738	2.378	46.113	42.086	41.949
96.154	8.127	17.548	4.214	4.802	12.793	2.319	46.363	42.921	42.792
99.359	7.889	17.895	4.270	5.036	12.903	2.085	47.039	43.883	43.774
102.564	7.716	18.178	4.437	5.212	12.904	2.027	47.296	44.634	44.525
105.769	7.493	18.404	4.604	5.448	13.069	1.851	47.402	45.358	45.251
108.974	7.375	18.687	4.660	5.682	13.125	1.675	47.655	46.021	45.904
112.179	7.265	18.910	4.772	5.918	13.127	1.500	47.622	46.566	46.432
115.385	7.154	19.133	4.940	6.095	13.237	1.382	47.592	47.107	46.955
118.590	7.040	19.414	5.052	6.331	13.348	1.207	47.699	47.747	47.576
121.795	6.988	19.635	5.165	6.567	13.351	1.031	47.525	48.186	47.985
125.000	6.936	19.800	5.277	6.744	13.517	0.796	47.358	48.532	48.307
128.205	6.773	19.911	5.334	6.979	13.573	0.679	47.325	48.967	48.741
131.410	6.777	20.130	5.447	7.216	13.684	0.503	47.014	49.305	49.039
134.615	6.775	20.297	5.448	7.392	13.742	0.211	46.996	49.571	49.283
137.821	6.722	20.463	5.560	7.570	13.744	0.094	46.834	49.911	49.601
141.026	6.669	20.628	5.672	7.745	13.909	0.024	46.677	50.250	49.916
144.231	6.671	20.738	5.673	7.919	13.965	0.200	46.523	50.413	50.060
147.436	6.559	20.905	5.785	8.092	14.021	0.435	46.509	50.843	50.478
150.641	6.557	21.073	5.785	8.266	14.075	0.494	46.500	51.098	50.713
153.846	6.617	21.180	5.786	8.440	14.186	0.730	46.208	51.161	50.748
157.051	6.675	21.343	5.842	8.615	14.187	0.847	45.923	51.308	50.860
160.256	6.619	21.455	5.898	8.731	14.189	1.082	45.915	51.560	51.103
163.462	6.618	21.567	5.844	8.904	14.244	1.200	45.898	51.724	51.254
166.667	6.620	21.676	5.899	9.021	14.408	1.435	45.753	51.880	51.391

```
10 REM
20 REM
30 REM                   *******************************
40 REM                   *******************************
50 REM                   ***    Prosram: CHAIN    ***
60 REM                   *******************************
70 REM                   *******************************
80 REM
90 CALL 3
100 DIM X1(17,17),Y1(17,17)
110 DIM X3(300),Y3(300),X4(300),Y4(300),X5(300),Y5(300)
120 DIM A$(80),B$(10),C$(80)
130 DIM D$(20),L$(20),Q$(10)
140 DIM R$(4),S$(4),T$(6)
150 DIM V$(20)
160 DIM D(20)
170 REM  ***********************************************************************
180 REM *                                                                     *
190 REM * Sub-prosram to senerate lookup table of correction factors.         *
200 REM *                                                                     *
210 REM ***********************************************************************
220 PRINT ""
230 PRINT "<7>"
240 PRINT "Wait ! ! !  The computer is now seneratins a lookup"
250 PRINT "table of correction factors."
260 PRINT "<7>"
270 PRINT ""
280 FOR I=1 TO 17
290 FOR J=1 TO 17
300 READ X1(I,J)
310 NEXT J
320 NEXT I
330 FOR K=1 TO 17
340 FOR L=1 TO 17
350 READ Y1(K,L)
360 NEXT L
370 NEXT K
380 REM
390 REM
400 PRINT ""
410 PRINT ""
420 PRINT "<7>"
430 PRINT "Type the name of the data file to be read:"
440 LINPUT Q$
450 IF Q$="" THEN GOTO 3150
460 PRINT "<11>         "
470 PRINT "                              <11><7><11>",Q$
480 PRINT ""
490 PRINT ""
500 PRINT "Type the first line number to be analyzed:"
510 INPUT Z1
520 PRINT "<11>        "
530 PRINT "                              <11><7><11>",Z1
540 PRINT ""
550 PRINT ""
560 PRINT "Type the last line number to be analyzed:"
570 INPUT Z2
580 PRINT "<11>        "
590 PRINT "                              <11><7><11>",Z2.
600 PRINT ""
```

```
610 PRINT ""
620 IF Z2=Z1 THEN GOTO 3150
630 IF Z2<Z1 THEN GOTO 3150
640 T$=Q$(1,2)
650 REM *******************************************************************
660 REM *                                                                 *
670 REM * Reading in measured constants for LED correction equations.    *
680 REM *                                                                 *
690 REM *******************************************************************
700 READ A1,A2,C1,C2,R1,R2,L3,L4,A3,A4
710 IF T$="G1" THEN GOTO 830
720 READ A1,A2,C1,C2,R1,R2,L3,L4,A3,A4
730 IF T$="G2" THEN GOTO 830
740 READ A1,A2,C1,C2,R1,R2,L3,L4,A3,A4
750 IF T$="G3" THEN GOTO 830
760 READ A1,A2,C1,C2,R1,R2,L3,L4,A3,A4
770 IF T$="G4" THEN GOTO 830
780 READ A1,A2,C1,C2,R1,R2,L3,L4,A3,A4
790 IF T$="G5" THEN GOTO 830
800 READ A1,A2,C1,C2,R1,R2,L3,L4,A3,A4
810 IF T$="E6" THEN GOTO 830
820 READ A1,A2,C1,C2,R1,R2,L3,L4,A3,A4
830 L$="AC "+Q$+",7F1"
840 CALL 4,L$
850 REM *******************************************************************
860 REM *                                                                 *
870 REM * Sub-program to read in data file from disk, and *
880 REM * to correct for addition of "128" to ASCII value *
890 REM * of last digit in each data column.                *
900 REM *                                                                 *
910 REM *******************************************************************
920 PRINT ""
930 PRINT "<7>"
940 PRINT "Wait ! ! !  The computer is now reading in the data"
950 PRINT "file from the floppy disk."
960 PRINT ""
970 PRINT "<7>"
980 FOR I=1 TO Z2
990 LINPUT ON (7)A$
1000 FOR N=6 TO 11
1010 A=N*5
1020 B$=A$(A,A)
1030 CALL 37,B$,V
1040 V=V-128
1050 CALL 36,V,B$
1060 B=A-4
1070 C=A-1
1080 V$=A$(B,C)+B$
1090 D(N)=VAL(V$)
1100 NEXT N
1110 X3(I)=D(6)
1120 Y3(I)=D(7)
1130 X4(I)=D(8)
1140 Y4(I)=D(9)
1150 X5(I)=D(10)
1160 Y5(I)=D(11)
1170 NEXT I
1180 REM *******************************************************************
1190 REM *                                                                 *
1200 REM * Sub-program to correct for Selspot lens distortions, and *
```

```
1210 REM * conversion from Selspot units to inches.              *
1220 REM *                                                        *
1230 REM ***************************************************************
1240 PRINT ""
1250 PRINT "<7>"
1260 PRINT "Wait ! ! !  The computer is now correcting for Selspot"
1270 PRINT "lens distortions, and converting from Selspot units to"
1280 PRINT "inches."
1290 PRINT ""
1300 PRINT "<7>"
1310 FOR W=Z1 TO Z2
1320 FOR Z=1 TO 3
1330 IF Z=1 THEN X=1023-X3(W)
1340 IF Z=1 THEN Y=Y3(W)
1350 IF Z=2 THEN X=1023-X4(W)
1360 IF Z=2 THEN Y=Y4(W)
1370 IF Z=3 THEN X=1023-X5(W)
1380 IF Z=3 THEN Y=Y5(W)
1390 M=INT(X/64)+1
1400 N=INT(Y/64)+1
1410 P=(X/64)-M+1
1420 Q=(Y/64)-N+1
1430 R=X1(N,M)+P*(X1(N,M+1)-X1(N,M))
1440 S=P*(X1(N+1,M+1)-X1(N+1,M))
1450 X=R+Q*(X1(N+1,M)+S-R)
1460 R=Y1(N,M)+P*(Y1(N,M+1)-Y1(N,M))
1470 Y=R+Q*(Y1(N+1,M)+P*(Y1(N+1,M+1)-Y1(N+1,M))-R)
1480 REM
1490 REM    "C"  is the conversion factor from tenths of millimeters
1500 REM    to inches.
1510 C=1/(10*25.4)
1520 REM
1530 REM    "D" is the factor for adjusting the distance from the
1540 REM    camera to the grid, from the initial calibration
1550 REM    distance, of 125 inches, to the actual test condition.
1560 REM
1570 D=125/154
1580 IF X<0 THEN X=0
1590 IF Y<0 THEN Y=0
1600 X=C*D*X
1610 Y=C*D*Y
1620 IF Z=1 THEN X3(W)=ABS(X-53)
1630 IF Z=1 THEN Y3(W)=Y
1640 IF Z=2 THEN X4(W)=ABS(X-53)
1650 IF Z=2 THEN Y4(W)=Y
1660 IF Z=3 THEN X5(W)=ABS(X-53)
1670 IF Z=3 THEN Y5(W)=Y
1680 NEXT Z
1690 NEXT W
1700 REM ***************************************************************
1710 REM *                                                        *
1720 REM * Sub-program to print out corrected and scaled data file. *
1730 REM *                                                        *
1740 REM ***************************************************************
1750 PRINT ""
1760 PRINT "<7>"
1770 PRINT "Wait ! ! !  The computer will now print out the corrected"
1780 PRINT "and scaled data file."
1790 PRINT ""
1800 PRINT "<7>"
```

65

```
1810 REM   At the time chosen as t=0, the following constants are set:
1820 V0=Y3(Z1)
1830 H0=X3(Z1)
1840 Y0=Y4(Z1)
1850 X0=X4(Z1)
1860 S1=X5(Z1)+R1
1870 S2=Y5(Z1)+R2
1880 Q1=X4(Z1)+C1
1890 Q2=Y4(Z1)+C2
1900 PRINT ON (2)"                                    "+Q$
1910 PRINT ON (2)""
1920 PRINT ON (2)""
1930 C$="          Tip     Tip      CG       CG       RH       RH        "
1940 D$="CG       DAR      DAR"
1950 C$=C$+D$
1960 PRINT ON (2)C$
1970 C$="  Time      X        Y        X        Y        X        Y        "
1980 D$="Ang     CPSC     IND"
1990 C$=C$+D$
2000 PRINT ON (2)C$
2010 C$=""
2020 D$=""
2030 C$=" (msec)  (in)     (in)     (in)     (in)     (in)     (in)     (d"
2040 D$="es)  (des)  (des)"
2050 C$=C$+D$
2060 PRINT ON (2)C$
2070 PRINT ON (2)""
2080 REM   Computation and conversion of LED positions to
2090 REM   desired locations.
2100 FOR U=Z1 TO Z2
2110 A8=ATN((Y3(U)-Y4(U))/(X3(U)-X4(U)))
2120 A9=ATN((V0-Y0)/(H0-X0))
2130 A=A8-A9
2140 T1=X3(U)+A1*COS(A)-A2*SIN(A)
2150 T2=Y3(U)+A1*SIN(A)+A2*COS(A)
2160 G1=X4(U)+C1*COS(A)-C2*SIN(A)
2170 G2=Y4(U)+C1*SIN(A)+C2*COS(A)
2180 H1=X5(U)+R1*COS(A)-R2*SIN(A)
2190 H2=Y5(U)+R1*SIN(A)+R2*COS(A)
2200 D8=ATN((T2-S2)/(T1-S1))
2210 D9=ATN((V0+A2-S2)/(H0+A1-S1))
2220 D=D8-D9
2230 T1=T1-Q1
2240 T2=T2-Q2
2250 G1=G1-Q1
2260 G2=G2-Q2
2270 H1=H1-Q1
2280 H2=H2-Q2
2290 T3=T1+A3*COS(A)-A4*SIN(A)
2300 T4=T2+A3*SIN(A)+A4*COS(A)
2310 B=ATN((T4-L4)/(T3-L3))
2320 A=A*(180/3.14159)
2330 D=D*(180/3.14159)
2340 B=B*(180/3.14159)
2350 T=(U-Z1)*(1000/312)
2360 PRINT USING "@@@.@@@",T,T1,T2,G1,G2,H1,H2,A,D,B
2370 PRINT ON (2) USING "@@@.@@@",T,T1,T2,G1,G2,H1,H2,A,D,B
2380 NEXT U
2390 REM ****************************************************
2400 REM *                                                  *
```
·66

```
2400 REM *                                              *
2410 REM * Lens correction data for the X-coordinates. *
2420 REM *                                              *
2430 REM ************************************************
2440 DATA -674,437,1545,2647,3744,4833,5914,7000,8087,9185,10273,11343
2450 DATA 12429,13541,14609,15641,16636,-721,414,1533,2635,3718,4808
2460 DATA 5899
2470 DATA 6990,8081,9164,10249,11338,12422,13499,14579,15660,16743,-749
2480 DATA 395,1517,2618,3692,4783,5882,6977,8070,9147,10232,11332,12415
2490 DATA 13474,14562,15672,16805,-758,379,1497,2594,3666,4758,5863,6960
2500 DATA 8055,9133,10220,11325,12409,13464,14556,15675,16823,-737,370
2510 DATA 1470,2561,3640,4735,5841,6939,8033,9125,10218,11315,12403
2520 DATA 13478
2530 DATA 14568,15668,16779,-736,355,1445,2533,3614,4710,5818,6918,8014
2540 DATA 9111,10209,11311,12402,13480,14568,15663,16764,-752,334,1421
2550 DATA 2506,3588,4683,5789,6892,7994,9092,10195,11311,12405,13474
2560 DATA 14561,15659,16768,-763,320,1405,2489,3573,4668,5775,6880,7984
2570 DATA 9083,10186,11304,12399,13467,14554,15653,16764,-772,311,1396
2580 DATA 2481,3565,4662,5771,6877,7982,9079,10180,11293,12387,13456
2590 DATA 14545,15646,16759,-787,300,1388,2474,3557,4655,5769,6873,7972
2600 DATA 9067,10167,11280,12374,13444,14531,15630,16739,-796,294,1383
2610 DATA 2470,3552,4650,5765,6867,7964,9057,10154,11263,12356,13428
2620 DATA 14517,15617,16730,-788,296,1381,2466,3549,4646,5756,6859,7959
2630 DATA 9051,10143,11240,12330,13407,14502,15610,16731,-819,285,1382
2640 DATA 2472,3549,4643,5749,6849,7949,9038,10128,11223,12312,13385
2650 DATA 14482,15599,16737,-891,263,1389,2488,3553,4639,5740,6835,7931
2660 DATA 9015,10105,11211,12299,13355,14453,15588,16762,-893,256,1381
2670 DATA 2482,3552,4640,5739,6833,7929,9011,10099,11199,12288,13353
2680 DATA 14447,15566,16713,-852,259,1364,2462,3550,4645,5743,6841,7938
2690 DATA 9020,10103,11189,12277,13372,14457,15536,16610,-770,271,1339
2700 DATA 2429,3547,4652,5753,6856,7957,9040,10118,11180,12268,13412
2710 DATA 14484,15499,16453
2720 REM ************************************************
2730 REM *                                              *
2740 REM * Lens correction data for the Y-coordinates. *
2750 REM *                                              *
2760 REM ************************************************
2770 DATA -1035,-1137,-1188,-1192,-1137,-1115,-1108,-1091,-1071,-1041
2780 DATA -1013,-981,-970,-992,-976,-933,-859,56,-9,-44,-48,-17,-2,5,23
2790 DATA 48,69,88,105,119,128,137,146,155,1168,1122,1097,1091,1108
2800 DATA 1118,1126,1145,1171,1186,1199,1206,1219,1246,1251,1240,1211
2810 DATA 2300,2261,2238,2230,2240,2248,2256,2273,2296,2309,2319,2320
2820 DATA 2332,2361,2364,2347,2309,3460,3406,3372,3361,3375,3384,3395
2830 DATA 3407,3421,3437,3448,3451,3456,3467,3471,3471,3467,4611,4555
2840 DATA 4522,4510,4524,4533,4543,4552,4560,4575,4585,4587,4591,4596
2850 DATA 4601,4607,4614,5756,5714,5688,5678,5688,5695,5702,5708,5715
2860 DATA 5724,5731,5734,5739,5748,5754,5758,5761,6896,6871,6855,6848
2870 DATA 6854,6857,6861,6864,6868,6873,6876,6877,6882,6891,6898,6903
2880 DATA 6907,8033,8029,8027,8025,8024,8023,8021,8022,8023,8023,8023
2890 DATA 8020,8023,8033,8041,8048,8054,9181,9199,9209,9211,9204,9202
2900 DATA 9202,9202,9200,9196,9189,9173,9172,9189,9200,9208,9212,10313
2910 DATA 10351,10373,10380,10367,10361,10359,10354,10348,10343,10334
2920 DATA 10313,10311,10330,10342,10351,10357,11421,11484,11522,11535
2930 DATA 11515,11503,11491,11477,11462,11458,11453,11443,11443,11456
2940 DATA 11467,11477,11486,12541,12611,12652,12665,12642,12628,12614
2950 DATA 12597,12579,12577,12572,12559,12557,12565,12576,12593,12616
2960 DATA 13673,13731,13763,13772,13751,13738,13727,13714,13699,13699
2970 DATA 13691,13667,13655,13651,13666,13701,13757,14739,14822,14867
2980 DATA 14878,14945,14830,14822,14809,14793,14792,14783,14753,14741
2990 DATA 14744,14756,14778,14812,15759,15890,15962,15978,15924,15904
```

```
3000 DATA 15902,15888,15869,15866,15855,15823,15815,15838,15842,15833
3010 DATA 15809,16736,16937,17047,17072,16990,16763,16967,16951,16927
3020 DATA 16921,16909,16877,16876,16931,16924,16867,16753
3030 REM *****************************************************
3040 REM *                                                   *
3050 REM * Measured constants for LED Correction Equations.  *
3060 REM *                                                   *
3070 REM *****************************************************
3080 DATA -1,-.44,0,0,-2.12,.69,6.06,2.44,-1.12,-.93
3090 DATA -1.31,1.06,.6E-1,0,-1.56,-1.31,4.06,3,-1.06,-.93
3100 DATA -1.31,.88,-.38,.88,-2.62,.5,3.75,2.31,-.87,-.94
3110 DATA -.75,1.12,0,-.75,-2.56,1.62,9,1.25,-1.13,-1.12
3120 DATA -1.69,.34,.16,.6E-1,.12,-.3E-1,8.69,.62,-1.13,-1.07
3130 DATA -1.25,0,.62,.5,-2.44,-.12,0,0,0,0
3140 DATA -1.75,.81,.19,.19,-.5,.19,6.06,.94,-.75,-.69
3150 CALL 3
3160 END
```

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using an Optoelectronic Measurement System

5. AUTHOR(S)
Donald Robinson and Charles Federman

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

In 1980 the Consumer Product Safety Commission initiated the in-house development of a mandatory standard to address chain saw kickback. Part of that effort involved relating known chain saw energy levels generated during kickback to the final angle that a saw might travel when held in the hands of a chain saw operator. The present report describes the experimental program developed at NBS 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. The measurement system employed in this research included a computer-controlled optoelectronic system for measuring the displacements of selected points on the test saws and test fixture during simulated kickbacks. Included in the report is a description of the test equipment and procedures, the experimental design, and analyses of the measured displacement data for chain saws having known values of kickback energy.

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

chain saw kickback motion; displacement measurements; kickback energy; optoelectronic measurement system; simulated kickback motion; volunteer test subjects.

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