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DETECTION OF MULTIPLE DOCUMENT MISFEEDS IN AUTOMATIC FEED MACHINES

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

David M. Melchers

August 1986

This thesis is dedicated to my Savior and Lord, Jesus Christ.

ABSTRACT

Multiple document misfeed occurs in an automatic feed machine when two or more documents are transported through the machine instead of one. The purpose of this project was to examine two types of systems (a cantilever beam and a rigid beam/spring system) as potential means of detecting these misfeeds.

To accomplish this, a model was developed for the document/detector impact assuming the document behaved as a spring/damper system affixed to a rigid, constant velocity beam. Given this model for the impact response, both designs were analyzed using dynamic considerations yielding a predicted response of the systems. These were verified experimentally.

It was found that the rigid beam/spring design was unacceptable (did not satisfy the given constraints), while the cantilever beam design provided an acceptable solution, the best of which is given below.

Beam thickness = 0.011 inches

Total beam length = 1.5 inches

Striking angle = 4 degrees

Preload = 0.27 pounds.

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LIST OF SYMBOLS AND ABBREVIATIONS

Note: These lists are representative, but incomplete. Other symbols and abbreviations referred to throughout the text are defined as used.

SYMBOLS

ω = angular velocity

r = radius

v = velocity

p = force

E = modulus of elasticity

I = moment of inertia

L = length

δ = distance

w = width

b = thickness

d = distance

t = time

T = torque

k = spring constant

ρ = density

c = damping coefficient

Δ = displacement

θ = angle

W = weight

Y = location of center of gravity

Z = distance

X = distance

ζ = damping ratio

A = constant

B = constant

K = constant

h = height

ABBREVIATIONS

rev = revolutions

g = grams

min = minutes

rad = radians

sec = seconds

rpm = revolutions per minute

in = inches

lb = pounds (force)

psi = pounds per square inch

deg = degrees

Hz = hertz

CHAPTER I

INTRODUCTION

1. BACKGROUND

The IBM 1255 check reader-sorter is used in small banks to sort financial documents by reading the magnetic numerical code printed on the document face. A separator mechanism initiates the transport of a document through a read area where the magnetic code is read, to a bay selector area where the documents are sorted. In the case of a multiple document misfeed, two or more documents overlap, entering the transport area together. When this occurs, only the top check is read. The lower documents would not be read and would be directed to the same bay as the upper check. If a multiple feed detector is included in the system, these checks may be directed to a reject bin for later sorting.

Multiple document misfeed is a serious problem, particularly in the banking industry with check reader-sorters, automatic tellers, and other machines that automatically feed documents. To minimize this problem, the document separator mechanism should be optimized to reduce multiple feeds. A typical separator mechanism is shown in Figure 1. Even with an optimal separator mechanism, it is practically impossible to completely eliminate multiple feeds particularly due to differences in document thickness and surface roughness and the potential for the document surface to be contaminated with foreign, "sticky" material. Because of this, some type of detector may be required to further reduce misfeed problems. The

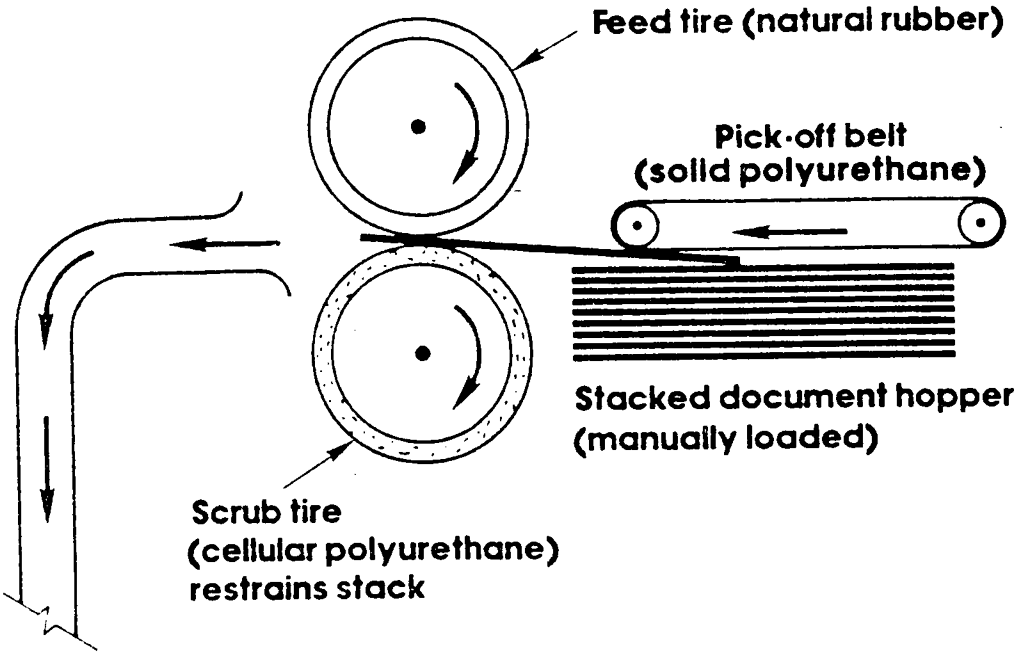


Figure 1. Example of separator mechanism.

Source: Michael D. Bessette, "Designing Reliable Paper-Handling Systems," Machine Design, 9 May 1985, p. 55.

IBM Corporation has funded this project in order to analyze the lever arm as a viable detector option. The vertical displacement of the lever arm can be tracked with an electronic probe to distinguish between a typical single feed response and a multiple document misfeed (see Figure 2 for typical response curves).

2. SPECIFICATIONS FOR ANALYSIS

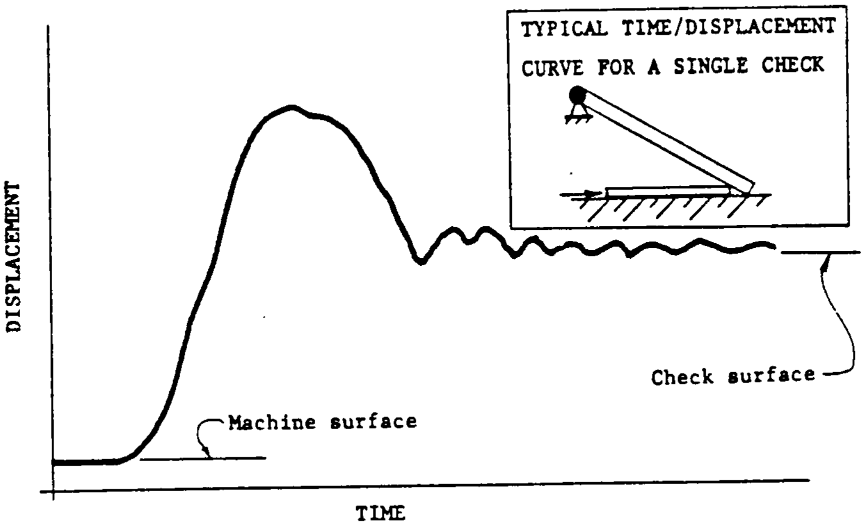
The following specifications were given to define the project's constraints and requirements:

(1) Document speed in the transport region was given as 150 ($\pm$ 15) inches per second. The actual velocity of the check in the machine used for testing was found to be 145 inches per second (see Appendix A for details).

(2) Single document thickness varies from 0.003 to 0.007 inches. Actual document thickness for experimentation was found using a micrometer.

(3) The detector device must be able to pass multiple documents with a maximum thickness of 0.100 inches without damage to the detector and without damaging or slowing down the documents.

(4) The detector must settle to within 0.002 inches above the document surface by 0.50 inches of check travel (3.33 milliseconds at 150 inches per second). This constraint is included so that there is distinct differentiation between a crumpled document and a multiple document misfeed so that electronic detection of misfeeds is possible.



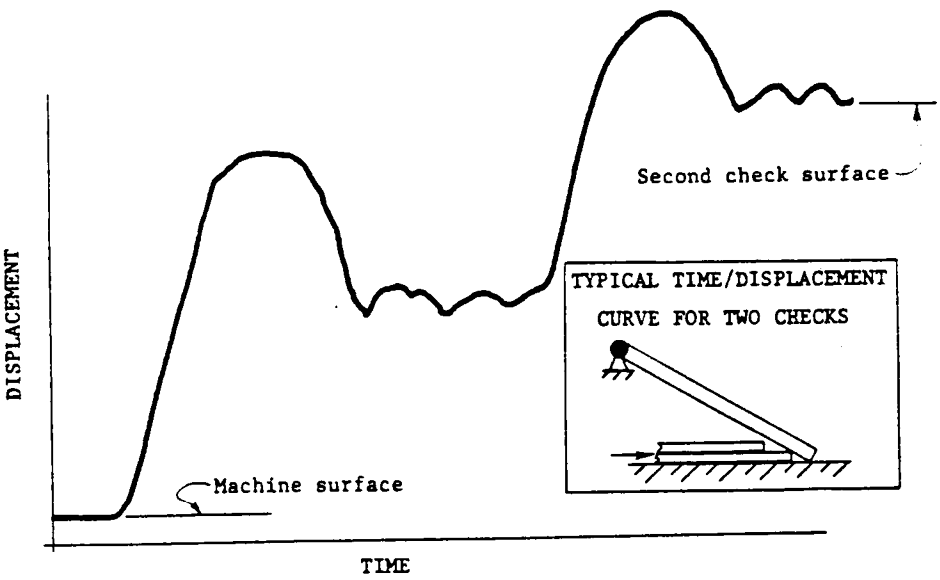


Figure 2. Comparison of single feed response to double feed response.

(5) The life of the detector must exceed 75 million operations (about 18 months of continuous use).

CHAPTER II

INITIAL STUDY OF SYSTEM

1. PRELIMINARY ANALYSIS

Upon inspection of the IBM 1255 reader-sorter, the optimal location for a detector device was determined to be in the lower transport region (see Figure 3). While there are different possible follower shapes and detector designs, one in particular will be analyzed in great detail because of its low cost and simplicity. This non-rigid cantilever beam design is shown in Figure 4. A rigid beam with a torsional spring was also analyzed (see Figure 5 for design).

To complete the preliminary analysis of the system, the maximum allowable force on a document such that documents are not slowed down or damaged was experimentally determined. The details of this analysis are in Appendix B. The maximum allowable force on the documents was determined to be 0.46 lb.

2. COMMENT ON LITERATURE REVIEW

Due to the specific and clear definition of the problem to be addressed in this project, no exhaustive literature search was performed at the outset of the project. However, as analysis proceeded, several sources were used in particular aspects of the analysis. These sources will be documented in the relevant sections where they are used.

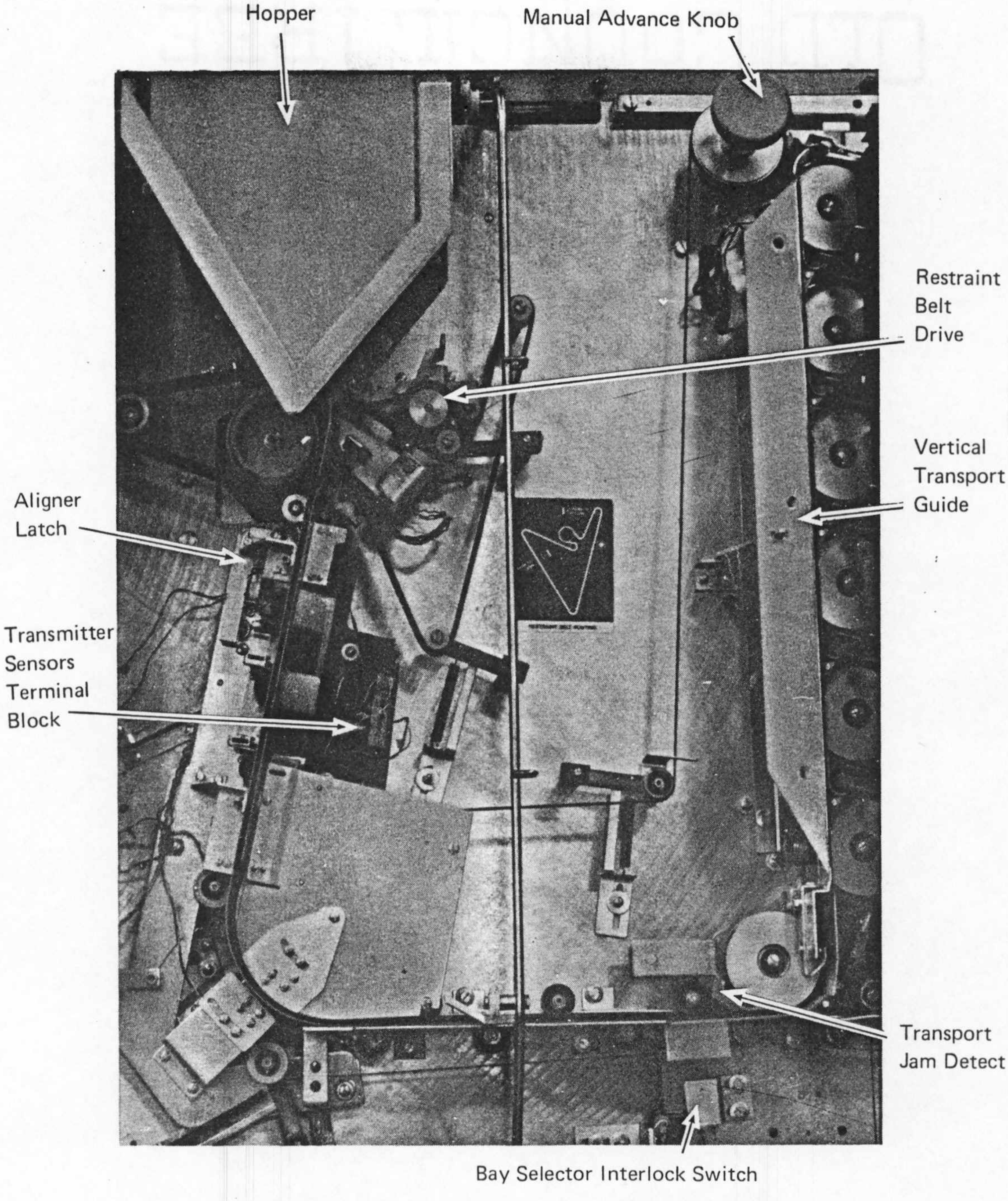


Figure 3. IBM 1255 reader-sorter transport area.

Source: IBM manual for the 1255 check reader-sorter, 18 August 1978, p. 9-1.

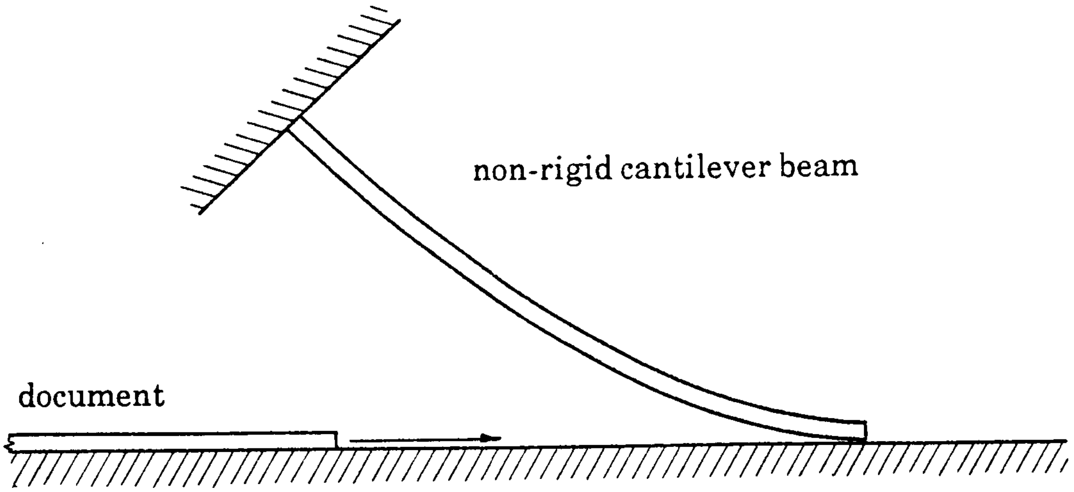


Figure 4. Cantilever beam design.

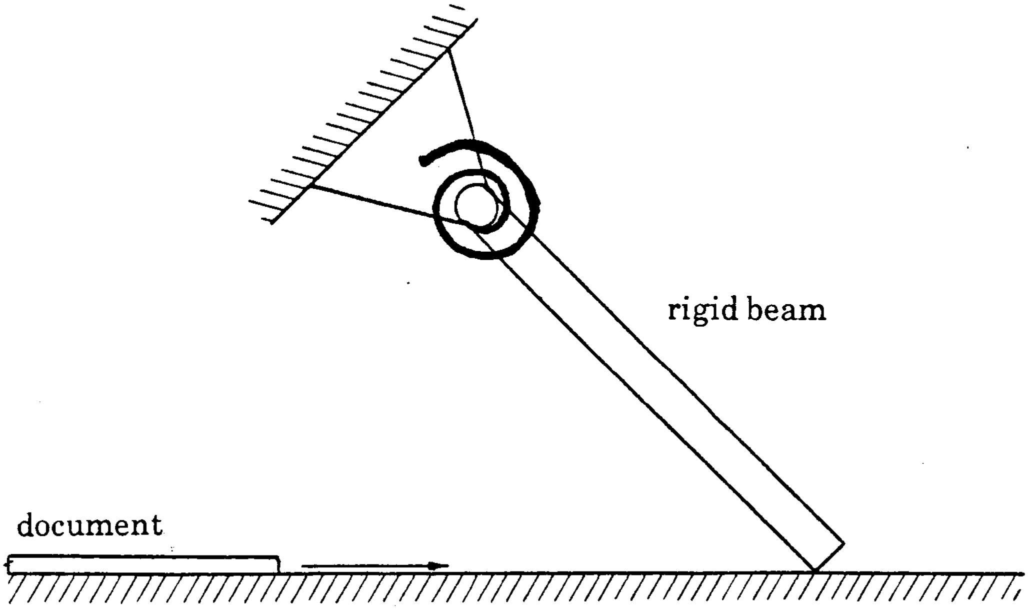


Figure 5. Rigid beam/spring design.

CHAPTER III

IMPACT RESPONSE MODEL

1. INTRODUCTION

To begin analysis of the detector/document system, a suitable model of the response of the detector upon impact is necessary. In particular, a model must be developed to describe the characteristics of the document as it strikes the detector. Several possible models were analyzed in order to arrive at an optimum and accurate model.

Shaw and Spencer[4] have researched the impulsive loading response of ideal fibre-reinforced rigid-plastic beams. In their analysis, they examine the response of beam when impacted by a mass which subsequently adheres to the beam. While this analysis is useful in gaining an understanding of the beam system, a better model for the impact response of the detector/document system seems likely.

An alternative is using the impulse force function, where the document can be described as transmitting a force to the detector instantaneously. The problems encountered with this model were complications in analysis and lack of accuracy in describing the actual physical system.

The most appropriate model in terms of accurately describing the physical system and ease of analysis was determined to be a spring/damper system.

2. SPRING/DAMPER MODEL

In using a spring/damper model, the document was considered to be a rigid, constant velocity beam and the end of the document was described as a spring/damper system incorporating the deflection of the impacted region of the document (see Figure 6 for representation).

A moment analysis about the point of rotation of the detector was used to describe the motion of the detector (see Appendix C for details). In particular, θ and $\dot{\theta}$ were expressed as functions of the system parameters (including the spring constant and damping coefficient associated with the document) and as functions of time. In order to simplify the ensuing analysis, a constant value for the damping coefficient was estimated ($c = .001$ lb-sec/in). Once this value was chosen, a computer program (included in Appendix O) was developed to find the initial angular velocity imparted to the rigid arm as a function of the spring constant associated with the document.

In order to provide an accurate estimate of the actual spring constant associated with any given document, a lever arm was built, mounted in the check sorter, and experimental values for the initial angular velocity of the arm were compared to the values obtained through the theoretical analysis. The previous choice of a damping coefficient was found to have little effect on the theoretical results, verifying this assumption.

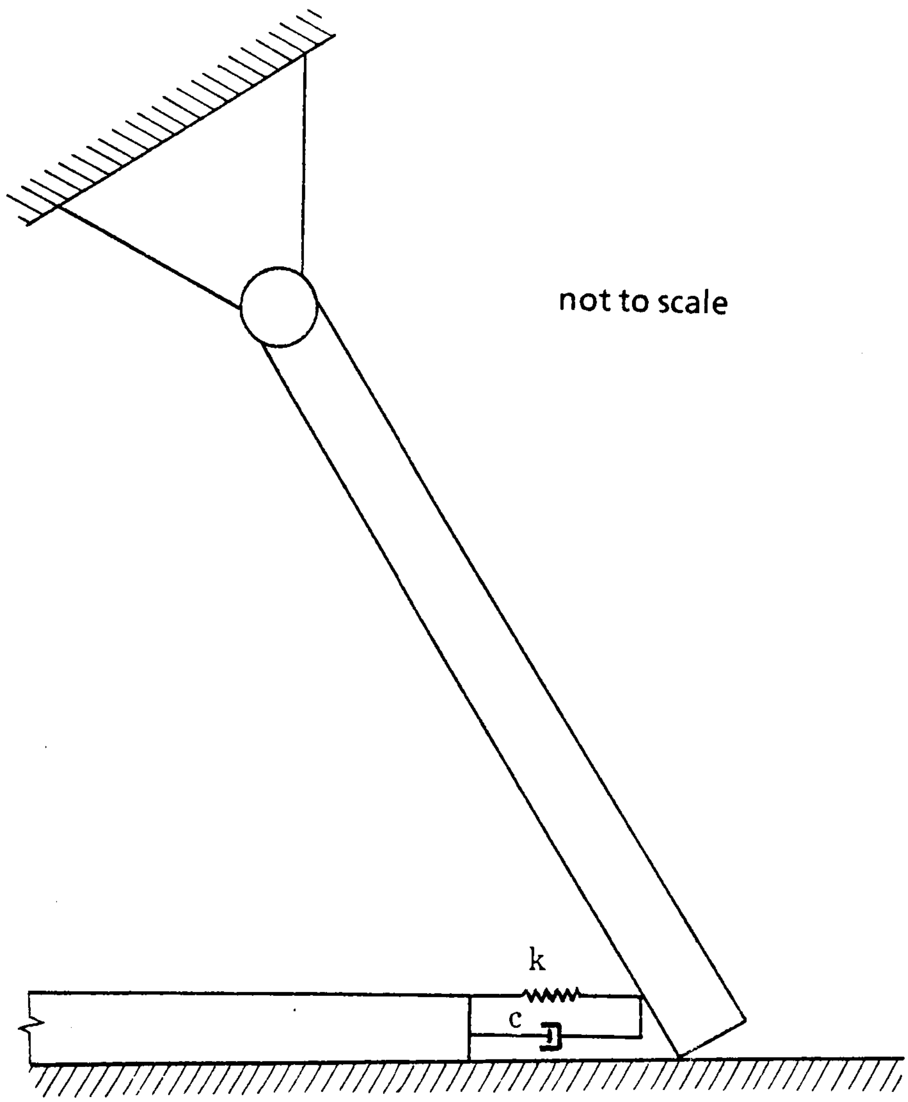


Figure 6. Document model.

3. EXPERIMENTAL SET-UP

To determine the response of a lever arm type detector upon impact by a document, a simple lever arm (length of two inches, width of .25 inches, thickness of .069 inches) was mounted at the detector site in the IBM 1255 check reader-sorter (see Figure 7). No spring was added to the rigid arm device, so the detector was free to swing upwards unrestrained. Holes were drilled in the arm near the end to accommodate optional added weight (increasing the moment of inertia of the arm). The angle at which the document strikes the detector, θ, was variable.

The change in beam parameters associated with adding weight is detailed below (W is the weight, I is the moment of inertia, and $\overline{Y}$ is the distance from the end of the beam to the center of gravity).

No additional weight	Additional weight at #1	Additional weight at #2
W = 0.0034 lb	W = 0.0140 lb	W = 0.0140 lb
I = 1.10 x 10^{-5} in-lb-sec^2	I = 5.01 x 10^{-5} in-lb-sec^2	I = 8.95 x 10^{-5} in-lb-sec^2
$\overline{Y}$ = 1.02 in	$\overline{Y}$ = 1.00 in	$\overline{Y}$ = 0.97 in

Values for the initial angular velocity of the arm were obtained for a variety of configurations. Details of determining the initial angular velocity of the arm experimentally are given in Appendix D. At least ten trials were run for any specific configuration to provide a maximum initial angular velocity and an average initial angular velocity experimentally. These

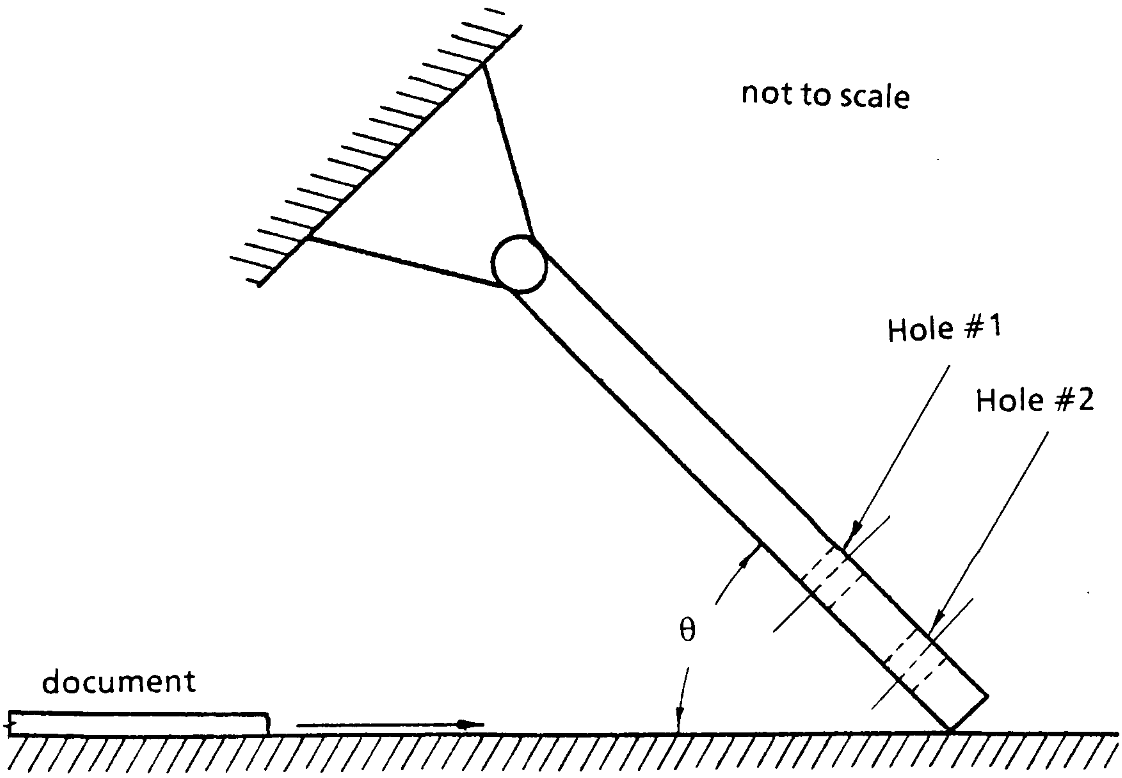


Figure 7. Experimental lever arm.

values were then compared to values obtained from the moment analysis of the system with the document having the spring/damper affixed.

To arrive at a value for the spring constant associated with any particular document, plots of $\dot{\theta}_i$ versus k were generated from the theoretical, computer analysis of the system for specific configurations and document types and the experimentally-determined values for the average $\dot{\theta}_i$ and the maximum $\dot{\theta}_i$ were superimposed on the plot. A typical plot is shown in Figure 8. The spring constants associated with three different document types were determined by comparing the above plots for at least five different configurations of the arm and arriving at a value of k which gives a value of $\dot{\theta}_i$ closest to the average initial angular velocity in all plots associated with any particular document. All plots are included in Appendix E.

4. RESULTS

From the plots in Appendix E, it is clear that an acceptable value for the effective spring constant of all three document types analyzed could be found. In order to accomplish this, a value of k was chosen such that the curve of $\dot{\theta}_i$ vs. k generated from the computer model nearly intersected the average initial angular velocity of the arm determined experimentally in all cases for any given document type. The effective spring constant of all three document types was found to be approximately 30 lb/in. This value will be used in all subsequent analysis.

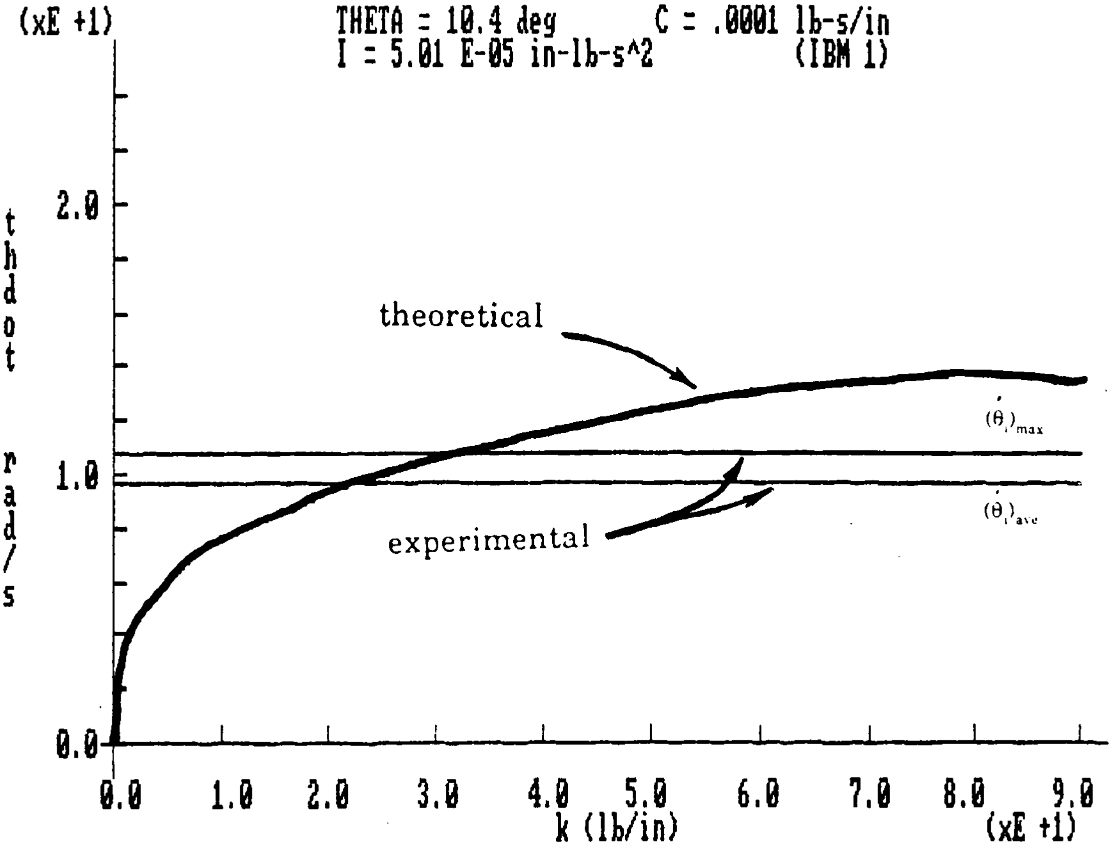


Figure 8. Typical plot of $\dot{\theta}_i$ versus k.

CHAPTER IV

ANALYSIS OF BEAM RESPONSE (CANTILEVER BEAM)

1. INTRODUCTION

Once an acceptable model for the document/detector impact was developed, the response of the beam could be analyzed. When a document strikes the lever arm (particularly a flexible lever arm), the actual motion of the beam is a summation of contributions of integer multiples of the fundamental frequency of the beam (see Figure 9). Normally, the fundamental frequency would dominate the motion, but it is quite possible that other modes of vibration may contribute substantially, particularly if the forcing function conforms the beam to a shape similar to that of one of its other natural modes. With an accurate model for document/detector impact, it is possible to predict the motion of specific points along the beam to insure that the probe is placed at a position over the beam that would have negligible contributions from higher order modes of vibration.

2. DISCRETE MODEL

The specific action of a beam impacted by a document will be theoretically analyzed by breaking the lever arm into discrete masses and solving for the displacement and angle throughout the beam. Previous analysis has required that the document/detector striking angle be small, therefore a transfer matrix analysis with a small angle assumption will be used. The general method of breaking up the beam is shown in Figure 10.

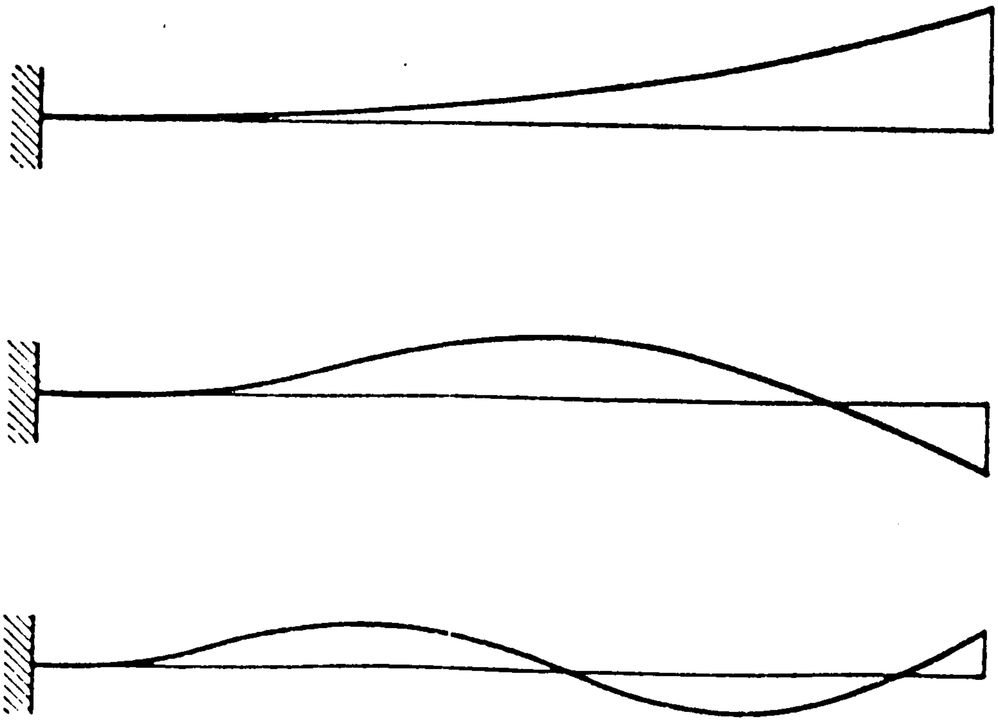


Figure 9. First three natural modes for a flexible cantilever beam.

Source: S. Timoshenko, D. H. Young, W. Weaver, Jr., Vibration Problems in Engineering, 4th ed. (New York: John Wiley and Sons, Inc., 1974), p. 427.

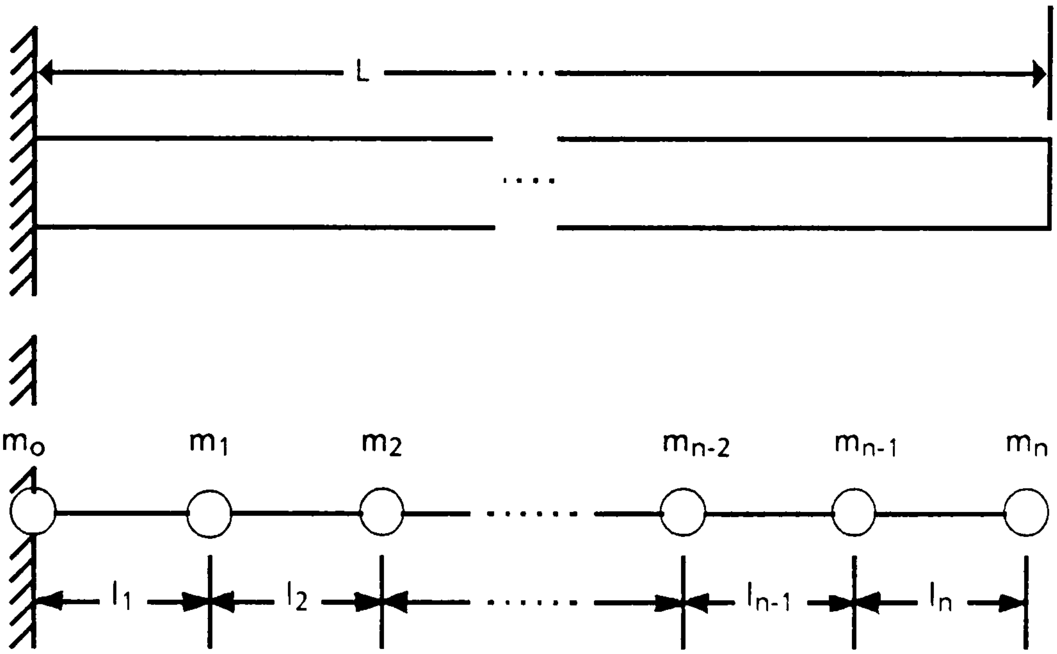


Figure 10. Discrete model of beam.

The following parameters are the relevant beam parameters (constant throughout the beam).

E is the modulus of elasticity.

W is the width of the beam.

T is the thickness of the beam.

M is the total mass of the beam.

L is the total length of the beam.

I is the area moment of inertia of the beam.

$$I = \frac{WT^3}{12} \tag{1}$$

The impact between the document and the detector will be modeled as occuring at the point where the beam contacts the transport base. Hence the beam will be described with a discrete mass at this point, a discrete mass at the imbedded end of the beam and discrete masses spaced equally throughout the rest of the beam (see Appendix F for expressions for the lengths and masses associated with this system).

3. DYNAMIC RESPONSE

Impact occurs at the mass point at the end disrupting the system so that there will be varying height, y_i, and angle, θ_i, associated with each mass, m_i, changing with respect to time. If one interior section of the beam is isolated away from both ends of the beam, an expression for the linear and angular velocities and displacements can be found as a function of the internal and external forces and moments acting locally. Details of the transfer matrix analysis are included in Appendix G.

The motion of the beam can be fully described by the following steps.

(1) The document strikes the detector. Given the spring/damper model for the document and recognizing that there is an initial detector preload, the detector would not move at the instant of impact.

(2) The detector would begin to lift off the base when the vertical force due to the spring/damper document system exceeds the vertical detector preload. The document would then continue to exert a force on the detector arm until the detector rises above the thickness of the document.

(3) After this time, the arm would rise above the document and then return towards the base.

(4) Eventually, the arm would return to the height of the document. When this happens, the arm would strike the document and bounce back up again with this reaction having a coefficient of restitution associated with it. (Appendix H includes the discussion of the coefficient of restitution.)

(5) The arm would continue to bounce on the document until the length of the document had passed under the detector.

A computer model was developed to predict the response of the detector arm using the previous five steps and using the results of the discrete analysis. This program predicts the exact linear and angular displacements and velocities of discrete mass points used to describe the lever arm, given a complete description of the dynamic and geometric parameters of this system. Runge-Kutta integration techniques were incorporated to solve for the dynamic response of the beam. The computer program is included in Appendix O.

4. EXPERIMENTAL SET-UP

This computer model was used to provide a theoretical prediction of the dynamic response of the system for a whole range of parameter values. From these response curves, a range of acceptable values for all of the parameters was determined. The criteria for determining this range were the physical feasibility of parameters (i.e. very large values for beam length were impossible given the working area) and the probability that given parameter values would satisfy the constraints of the system (particularly the settling time requirement). The latter criterion involved using both the response curves and intuition. The following parameter ranges were chosen for experimentation.

Beam length:	1.00 in to 1.75 in
Striking angle:	3 deg to 10 deg
Beam thickness:	.008 in to .012 in
Preload:	.05 lb to .30 lb

A constant value for the beam width ($\frac{1}{2}$ inch) and constant material properties (shim steel) were used because shim steel feeler gauge was available at a low cost.

Once these values were decided upon, experiments were run. The equipment used and the particular experimental set-up is shown in Figure 11. The feeler stock was cut to the required length and the end was bent to

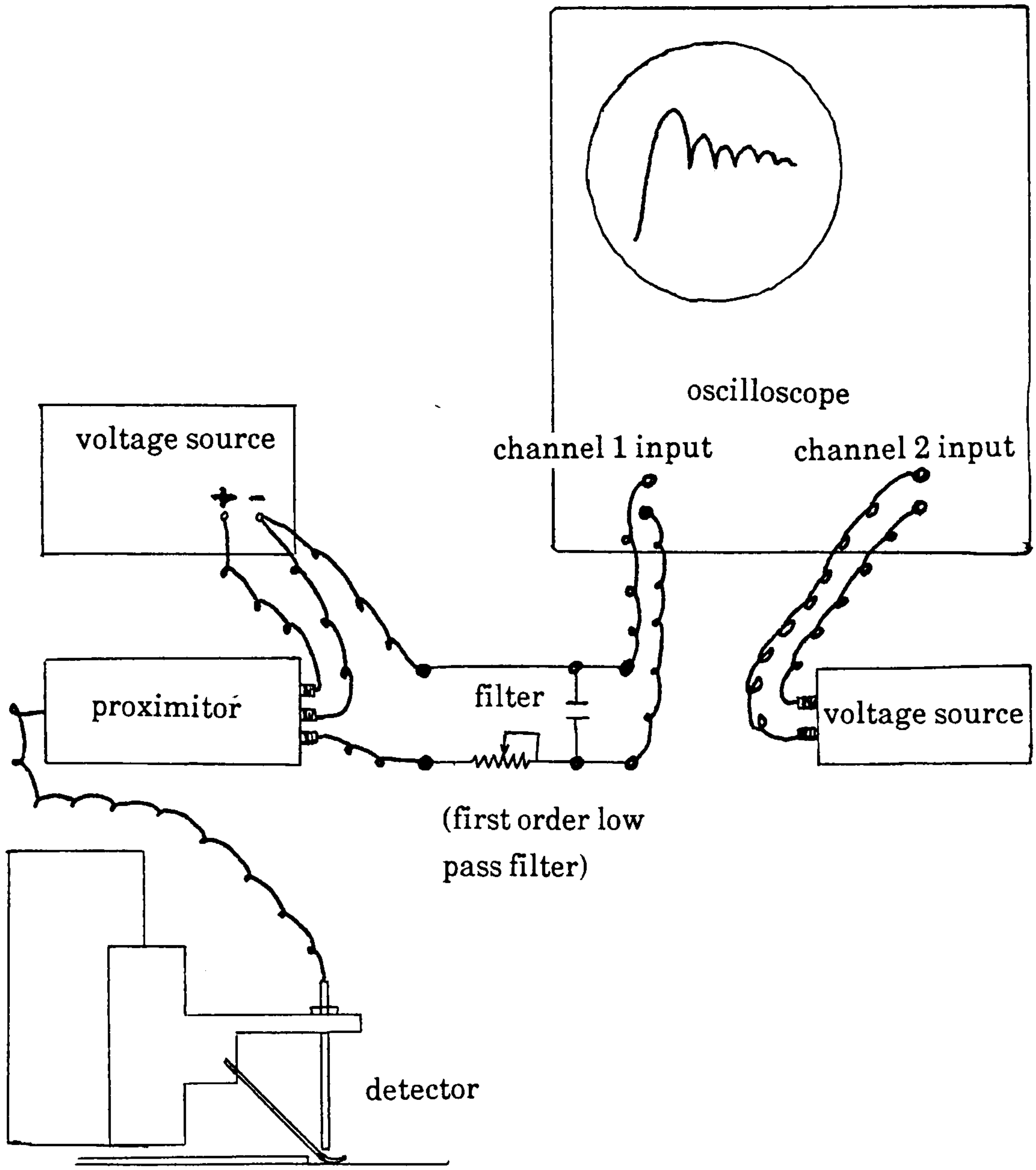


Figure 11. Experimental set-up.

decrease the impact angle and to protect the document from burrs. The detector arm was then mounted into its holder and tested for its dynamic properties. In particular, the logarithmic decrement and the natural frequency were calculated. Details of this procedure are given in Appendix I. A striking angle and preload were chosen in the acceptable range of values. The angle of the beam at the point where the beam was mounted was determined by an interactive computer program (included in the exhaustive program mentioned earlier) given the striking angle and the required preload.

Next, the detector holder was mounted to the side plate in the lower transport region of the machine with the values for mount angle of detector and striking angle corresponding to the calculated values. An eddy current probe was placed above the end of the beam. This probe produced a variable voltage depending on the proximity of the beam and was therefore used to record the motion of the detector on the oscilloscope.

A separate power supply was used in order to bring the response of the probe onto the oscilloscope screen. Also, the output voltage of the probe was run through an electronic filter to reduce the vibration effects.

5. VIBRATION EFFECTS

The moving parts in the reader-sorter will generate vibrations throughout the machine at a variety of frequencies. This noise may cause distinct problems with a lever-arm type detector, particularly with the electronic monitoring of the beam displacement. Several sources of vibrational noise exist in the system.

The moving parts of the machine will attenuate the noise caused by the motor, so that at the detector site in the lower transport region, vibration peaks would be expected to occur at integer multiples of the fundamental frequency of the motor (1725 rpm). Also, the line current into the motor is 60 Hz. Because this incoming current is alternating current, the coils of the motor will contribute vibrations at the harmonics of this 60 Hz signal.

Another source of noise will be produced by documents passing over the base plate. While this would cause low frequency noise over the base plate, it would have negligible effect on other sites tested in the lower transport region.

To illuminate the effect of vibrations, an accelerometer was placed at three different sites in the lower transport region of the reader-sorter and also on the probe holder. This signal was amplified and a frequency spectrum (magnitude of acceleration vs. frequency) was plotted at these sites. Plots are given in Appendix J. Plots were generated by the Hewlett Packard 5420 B Digital Signal Analyzer.

To find the exact magnitude of the acceleration response, a calibration curve for the accelerometer was produced. The accelerometer was attached to a shaker with a one g peak to peak acceleration. The calibration curve is plotted in Figure 12.

With the calibration curve, the magnitude of the peak to peak acceleration can be found at the various sites for different frequencies. Given the acceleration of a specific frequency, the displacement can be found by relating the displacement and the acceleration (see Figure 13 and following explanation).

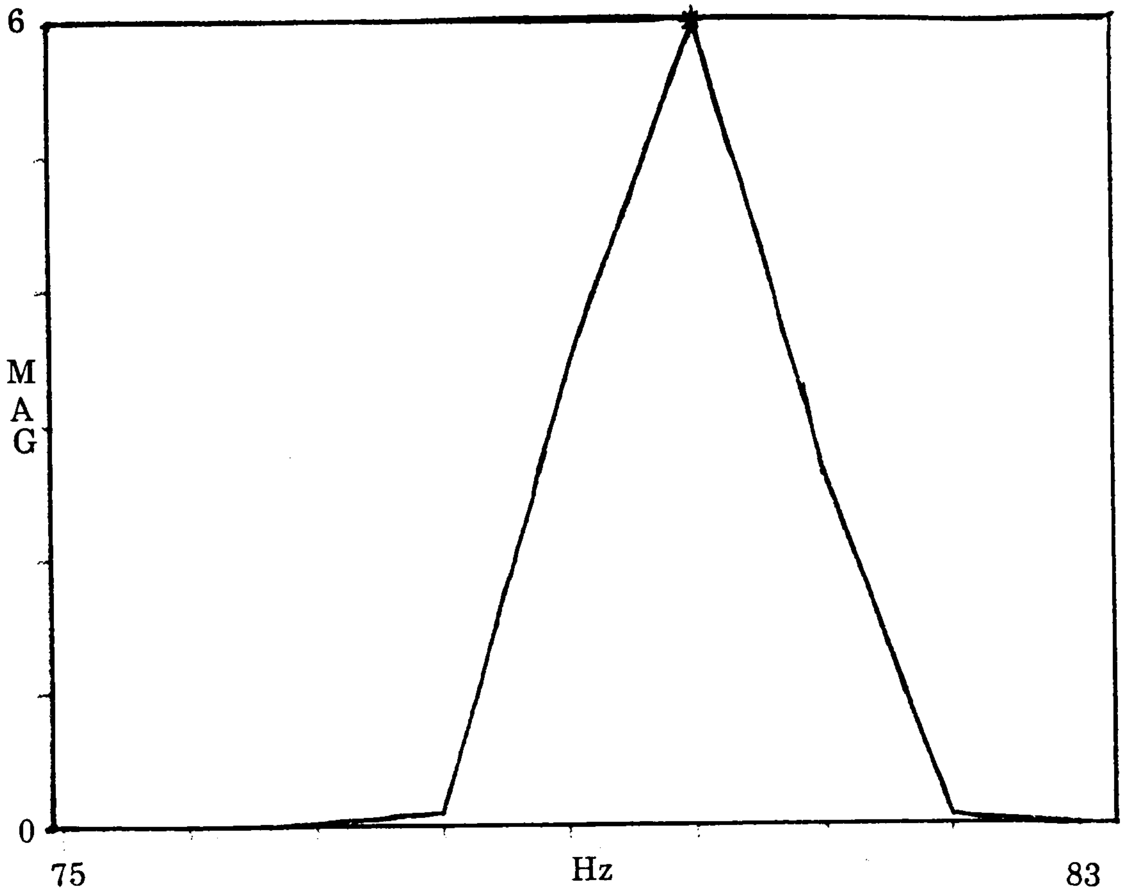


Figure 12. Calibration curve for 1 g peak to peak input.

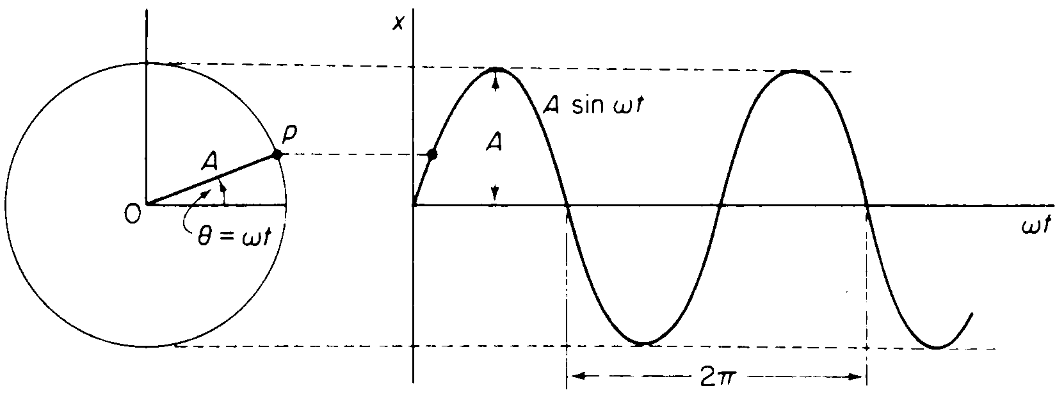


Figure 13. Harmonic motion.

Source: William T. Thomson, Theory of Vibration with Applications, 2nd ed. (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1981), p. 3.

In the case of harmonic motion

$$x = A \sin wt \tag{2}$$

Differentiating twice:

$$\ddot{x} = -w^2 A \sin wt = -w^2 x \tag{3}$$

where: w = 2π (frequency) = 2πf.

Therefore, the displacement can be described in terms of the acceleration as follows.

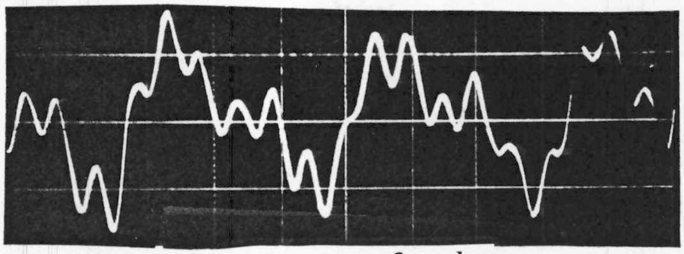
$$|x| = \frac{|\ddot{x}|}{w^2} \tag{4}$$

$$x_{mag}(in) = \frac{\ddot{x}_{mag}(g)}{\left[2\pi f(Hz)\right]^2}\left[\frac{386\,\frac{in}{sec^2}}{1\,g}\right]\left[\frac{1}{6}\right] = 1.63\,\frac{\ddot{x}_{mag}}{f^2} \tag{5}$$

The one-sixth term comes from the calibration curve.

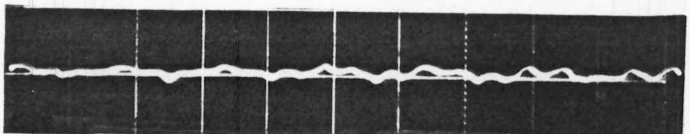
The main contribution of the vibration effects was found to be due to the movement of the probe holder. To reduce this vibration, a clamp was pushed against the mount, restricting side-to-side motion. This effect is shown in Figure 14.

To further reduce the noise in the system, an RC first order low pass filter was included in the system.



Vibration of probe

Base clamped down



Vise pushed against probe mount

Figure 14. Effect of restricting probe mount motion.

Note: Same amplitude scale.

6. EXPERIMENTAL RESULTS

Numerous beams were tested initially in order to arrive at an optimal beam design. After these initial tests, 19 different beam designs were tested and the responses on the oscilloscope for these tests were recorded by taking a Polaroid picture of the trace. The effects of filtering were examined and recorded. The pictures comparing the filtered and unfiltered response curves are included in Appendix K. The RC low pass filter passes a low frequency signal while filtering out high frequency noise. The optimal value for the time constant was found to be .001 seconds.

Pictures were also taken of the detector response to a crumpled check as compared to the response to a double feed. In all cases, there were easily observed differences in misfeed response as compared to the crumpled check response.

Finally, the initial experimental response of the beam was compared to the response predicted from the computer program. Appendix L includes a comparison of theoretical and experimental response of numerous beams.

An optimal design for the detector would yield a response that would have the smallest possible value for settling time while satisfying all other system constraints.

To decrease settling time, the four relevant variables would be changed as follows: increase beam thickness, decrease beam length, decrease striking angle, increase preload.

Given all previous analyses, an optimal beam design was chosen.

7. OPTIMAL BEAM DESIGN

The characteristics of the optimal design are given below.

beam thickness = .011 in.

total beam length = 1.5 in.

length from pivot point to base = 1.25 in.

striking angle = 4 deg.

preload = .27 lb.

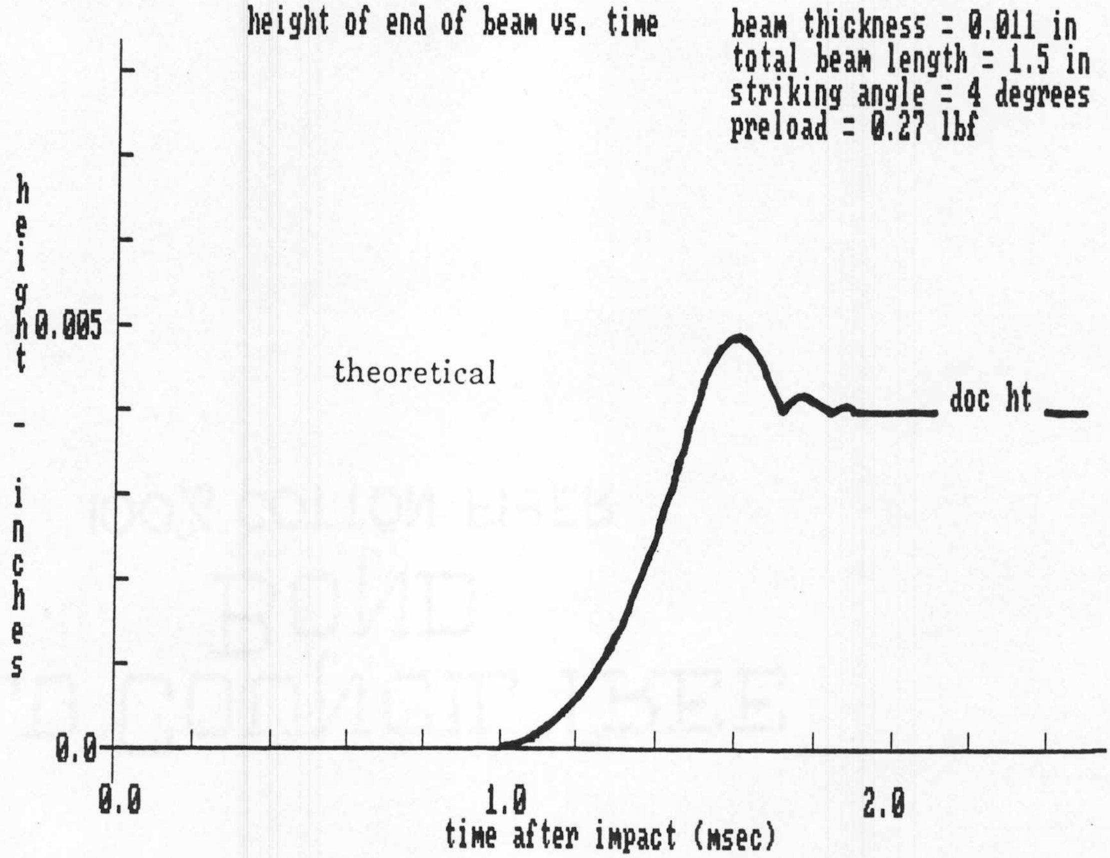
logarithmic decrement = .0430

damped natural frequency = 916.3 rad/sec

For this optimal beam design, the detector only rises approximately .0004 inches (10% of the document thickness) above the document surface and thus has a zero settling time. Figure 15 elucidates this point, comparing the experimental results of the impact response with three different time scales to the predicted theoretical response. The figure shows that this design does, in fact, have zero settling time and that the computer model is a good prediction of the experimental results.

Figure 16 compares the experimental results showing the complete traverse of the document for documents of different thickness and density. For all of the documents, the settling time is equal to zero.

Figure 17 shows the effect that filtering had on the optimal beam response. The lower trace is the response with no filtering. The middle response is optimal filtering (RC=.001 seconds). The upper response is twice optimal filtering. As can be seen, for optimal filtering the impact



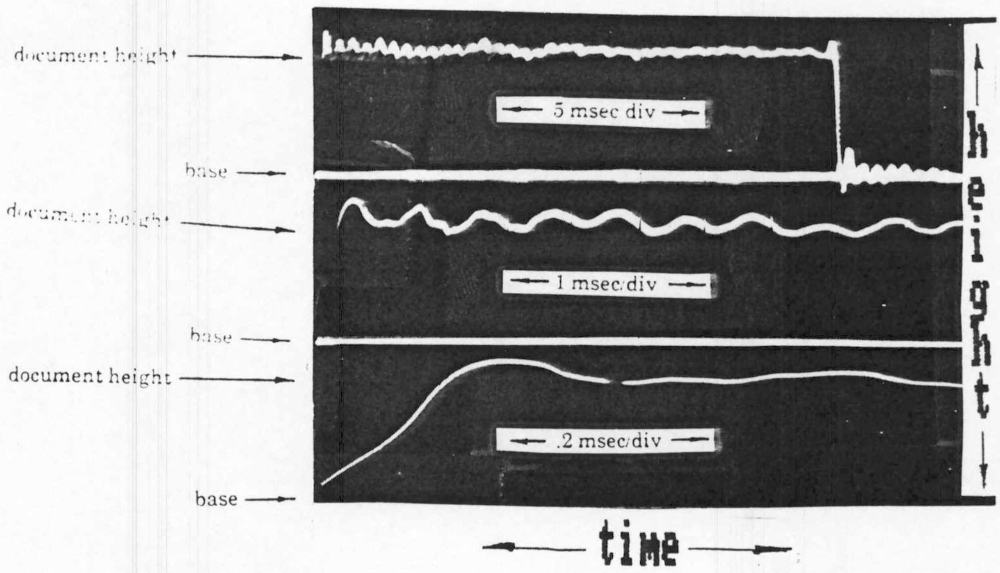


Figure 15. Comparison of experimental and theoretical responses for optimal beam design.

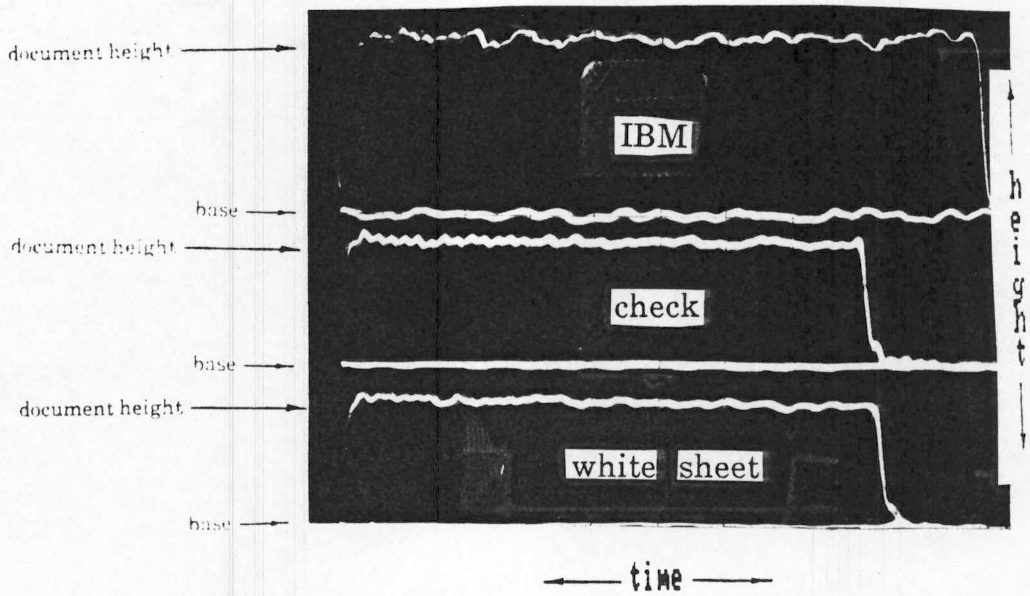


Figure 16. Traverse of three different documents

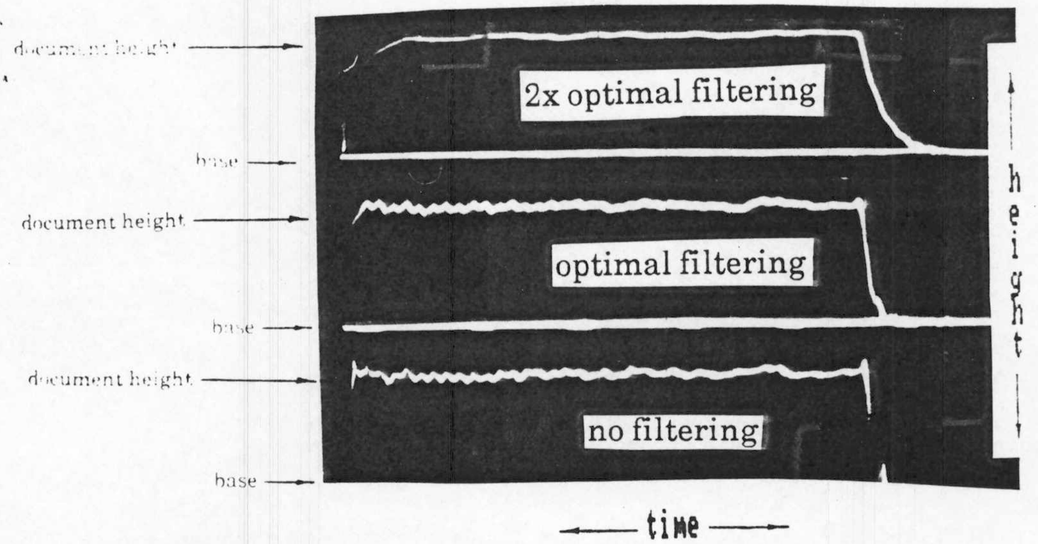


Figure 17. Effect of filtering on optimal beam design response.

response is very nearly vertical upon impact and when the document has traversed under the detector. Twice optimal filtering reduces this initial and final slope substantially.

Figure 18 confirms the differentiation between a creased or crumpled check and a misfeed response.

8. STRESS ANALYSIS

Once the optimal beam design has been found, the only remaining constraint is that the detector would not fail before 75 million operations. To verify this, a stress analysis was performed on the system. This included evaluating both the bending stress in the beam and the fatigue stress using the Soderberg criterion (see Appendix M for complete discussion).

The Soderberg criterion assumes a sinusoidal variation between the maximum and minimum stress on the beam. The minimum stress occurred when no documents passed under the beam. The maximum allowable thickness to traverse under the detector is .1 inches (25 documents at once). While it is physically possible that this many documents could pass, it would be inappropriate to assume that misfeeds of this type are regular. A more accurate deflection was chosen corresponding to the thickness of 2.5 documents. Table 1 shows the effect on the factor of safety of changing this thickness. With these considerations, the factor of safety was such that infinite life was expected.

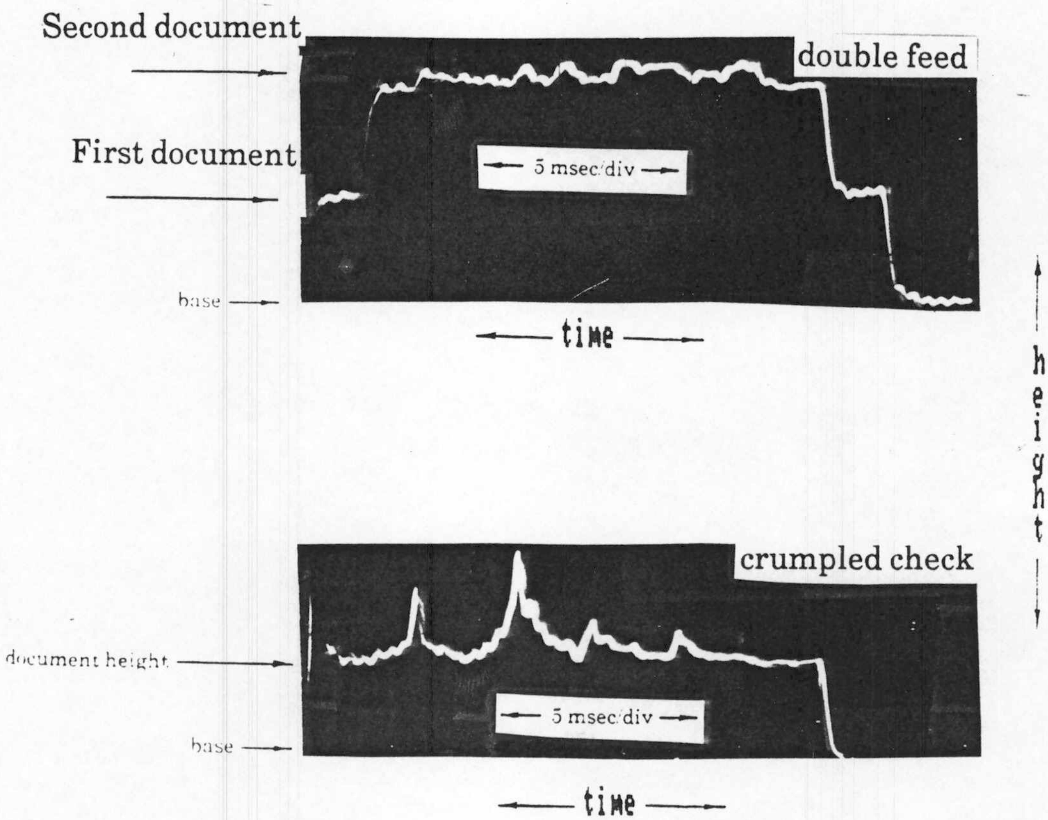


Figure 18. Comparison of crumpled check to double feed.

Table 1. Effect on factor of safety of changing thickness used in maximum stress calculation.

Number of documents used for maximum stress calculations	Thickness (inches)	Maximum stress (psi)	Factor of Safety (yield)	Factor of Safety (fatigue)
25	.10	61983	1.05	.70
20	.08	55783	1.17	.82
15	.06	50825	1.28	.94
10	.04	44627	1.46	1.15
5	.02	39668	1.64	1.40
2.5	.01	37190	1.75	1.58

Note: Factor of safeties calculated for infinite life.

9. DISCUSSION

The optimal beam design sufficiently satisfies all the given requirements and constraints on the system. The optimal beam yields an output signal which closely tracks the document surface.

Also, an accurate model for predicting the time response of discrete mass points on the detector was introduced. This computer model could be used for further analysis.

CHAPTER V

RIGID BEAM/SPRING RESPONSE

1. INTRODUCTION

In addition to the cantilever beam design, the rigid beam/spring design was also examined. The thickness of the detector arm was increased so that it functioned as a rigid arm and a torsional spring was affixed to the arm to restrict motion.

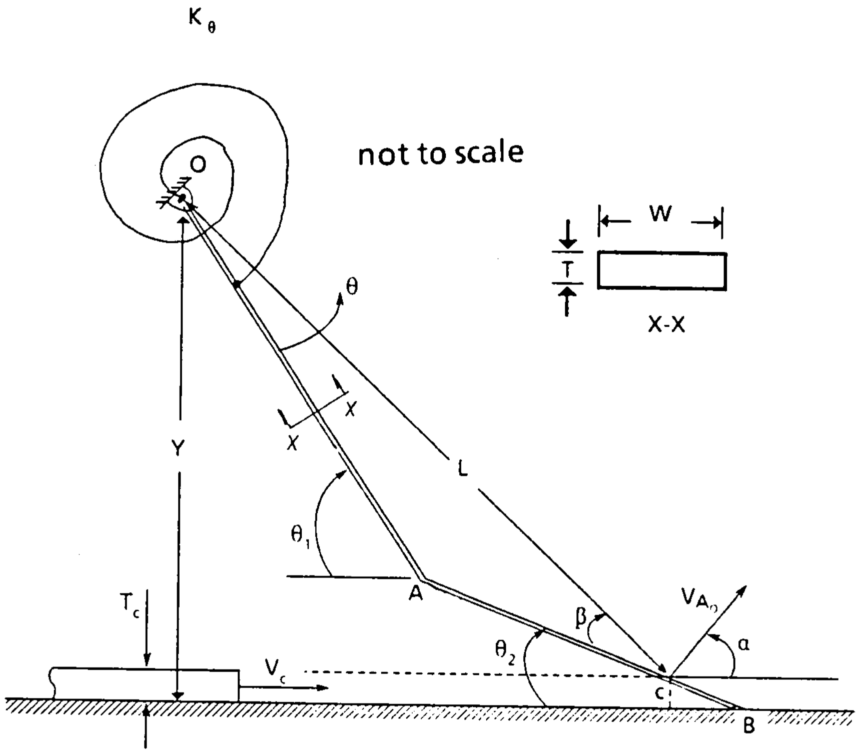
The procedure for analyzing this system was similar to that of the cantilever beam design. That is, given a model for the document, the motion of the beam can be determined by dynamic analysis.

2. DYNAMIC ANALYSIS

The complete design for the rigid beam/torsional spring combination with all parameters defined is shown in Figure 19. The analysis proceeds as before except that the preload is now due to rotation in the spring as opposed to bending in the cantilever beam. The equation describing the motion of the arm is then of the form

$$\ddot{\theta} + c\dot{\theta} + k\theta = k_1 + k_2 t \tag{6}$$

The constants were solved in this equation given the parameters in Figure 19 summing moments as for the cantilever beam. A computer



Definition of variables:

T_c is the document thickness. For computer analysis, $T_c = 0.005$ inches.

V_c is the velocity of the check. The actual velocity of the check in the machine used for testing was found to be 145 inches per second.

θ_1, θ_2 are the angles from the horizontal of the upper and lower constituents of the rigid beam, respectively.

OA, AB are the lengths of the upper and lower constituents of the rigid beam, respectively.

L is the length from the pivot point to the point where the check strikes beam.

K_θ is the torsional spring constant of the spring.

V_{Ao} is the initial velocity of the beam imparted by the impact of the check.

α,β are sufficiently described on the Figure.

θ is the angle of rotation of the beam.

Figure 19. Rigid beam/spring design.

program was written to predict the response of the system from Equation 6 (given the solution in Appendix C). This program is included in Appendix O. After the computer program was developed and run for many different designs, it became obvious that the predicted response would not satisfy the constraints on the system except for some extreme cases (i.e. very small beam thickness, which would invalidate the assumption that the beam was rigid). Particularly, for the detector to settle within the given time constraint, the preload was required to exceed the maximum allowable force on the check. While this predicted response was clear, it still remained to verify this model.

3. EXPERIMENTAL RESULTS

The rigid beam was mounted in the lower transport region of the 1255 with a torsional spring at its base. Three different beam/spring designs were tested to verify the theoretical model. A beam was chosen of sufficient thickness (.125 inches) to insure that it would function as a rigid beam. The width and length of the beam were .5 inches and 2.125 inches, respectively. Using this beam, three different springs were mounted on the base of the beam as described below.

Trial	Spring constant (in-lb/rad)	Preload torque (in-lb)
1	.8	1.275
2	.5	.40
3	.1	.15

As Figure 20 confirms, for all three cases, the predicted response very nearly describes the actual experimental results. Also, none of these conditions satisfied the required constraints. The first design settled in time, but had a preload exceeding the maximum allowable preload considerably. The other two designs did not settle in time. Table 2 compares the settling time and percent overshoot of the theoretical and experimental results.

4. DISCUSSION

While the rigid beam/spring design may be appropriate for other applications, it did not satisfy the constraints of the system and is therefore an unacceptable design. This is because the rigid beam is a heavy device with a relatively large moment of inertia. Therefore, a large preload is required for the beam to settle in time. However, all acceptable preloads (for small settling times) would not allow the documents to pass through freely.

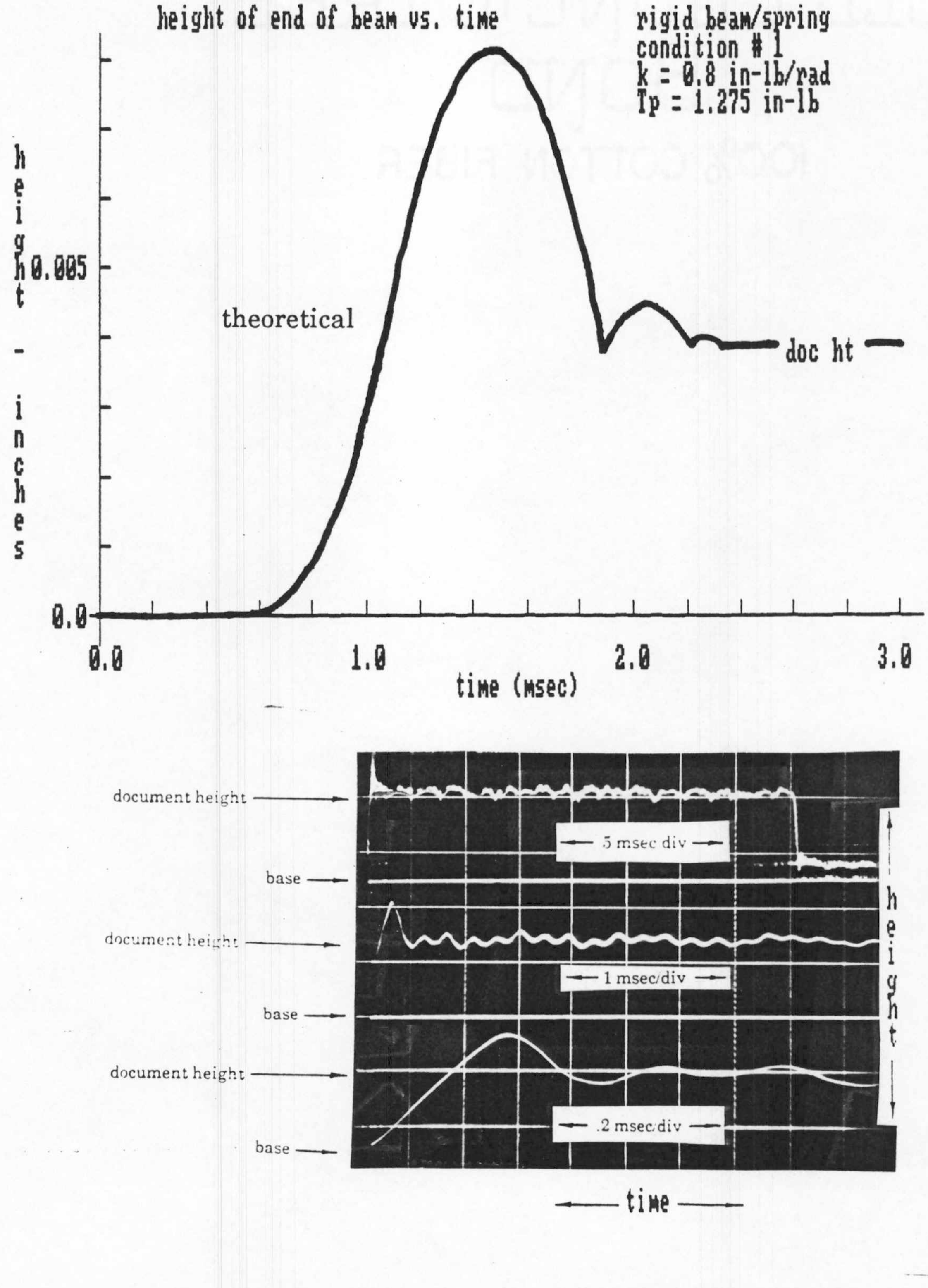


Figure 20. Comparison of experimental and theoretical responses for rigid beam/spring design.

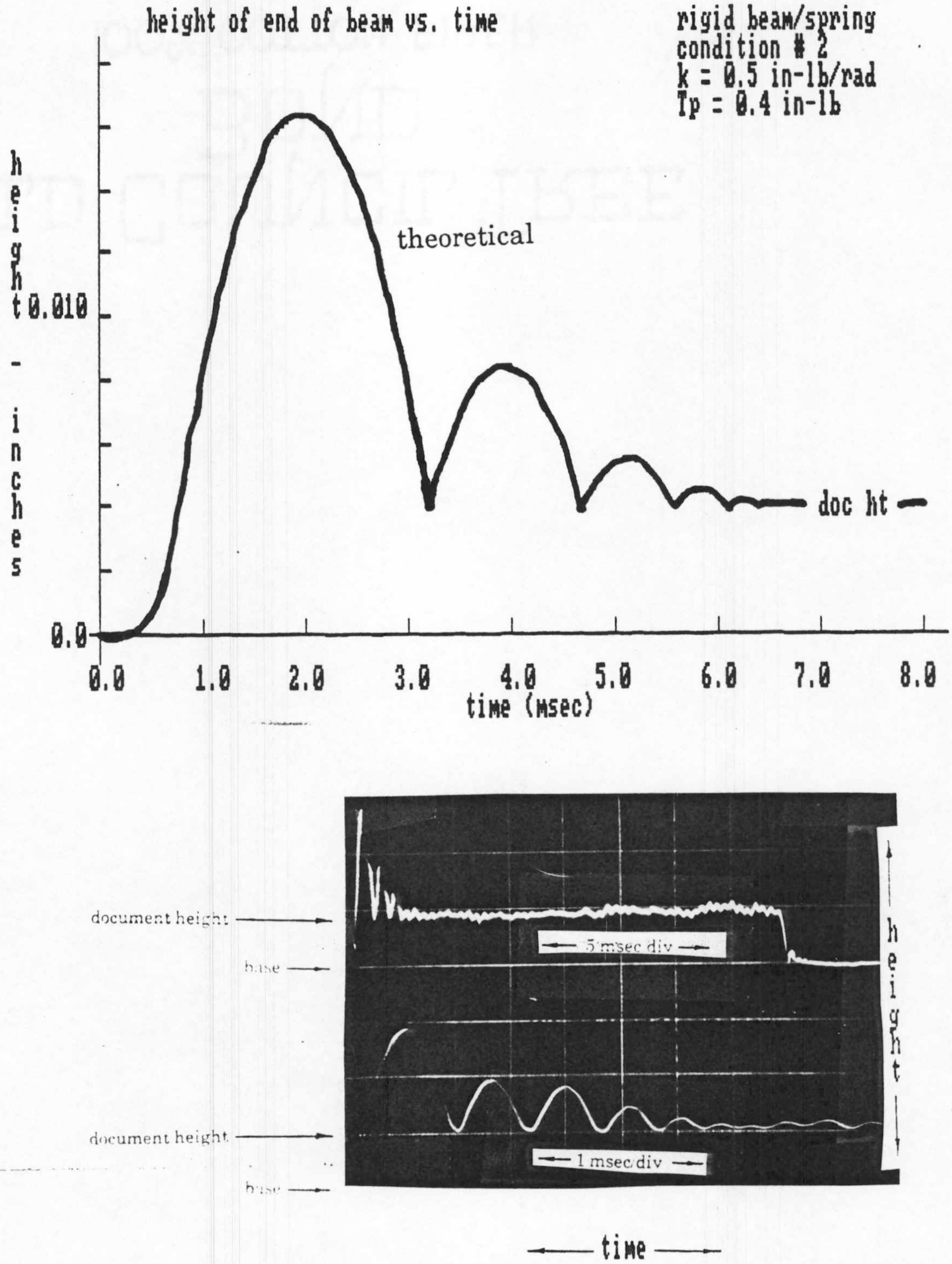
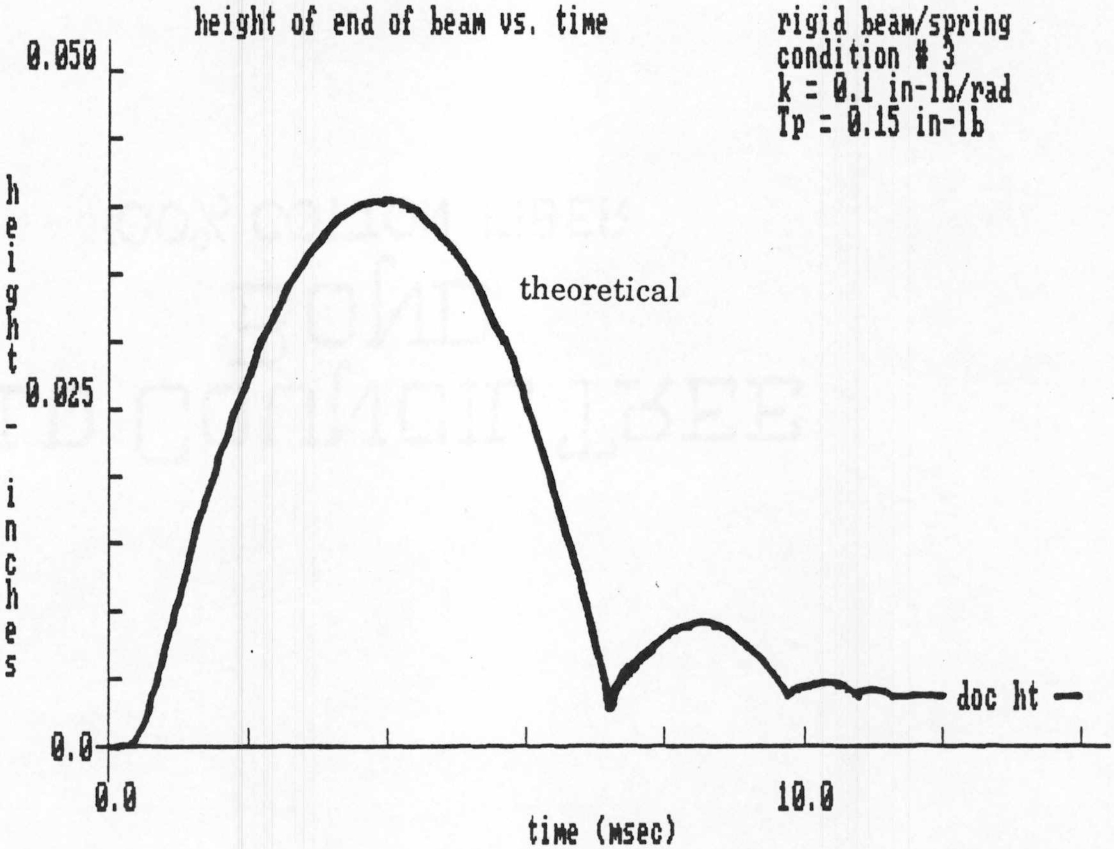


Figure 20 (continued).



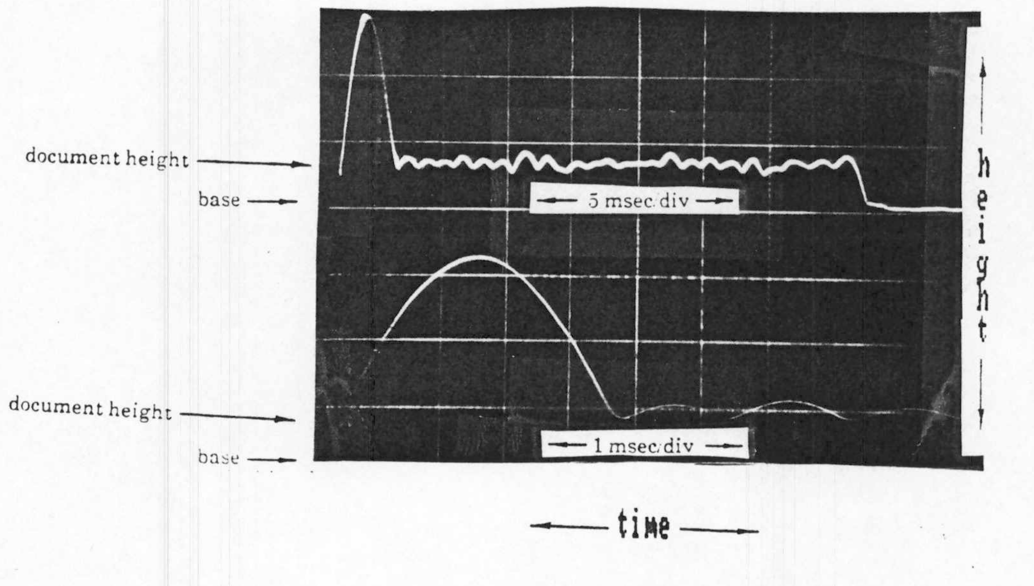


Figure 20 (continued).

Table 2. Comparison of theoretical and experimental results for rigid beam.

spring constant	preload	% overshoot		rise time to max. height (msec)	
(in-lb/rad)	(in-lb)	theoretical	experimental	theoretical	experimental
0.8	1.275	52	42	0.9	0.5
0.5	0.4	74	70	2.0	1.0
0.1	0.15	93	72	2.0	2.0

CHAPTER VI

SUMMARY

1. CONCLUSIONS

The intent of this project was to examine two possible designs to detect misfeed response in automatic feed machines, particularly the IBM 1255 check reader-sorter. As has been discussed, the cantilever beam design yielded very good results, while the results from the rigid beam/spring design were unacceptable. In addition to this, the cantilever beam is a better design for a few other reasons. First of all, the cantilever beam in itself, is a very simple, inexpensive design, involving only two parts (beam and mount) and costing a few dollars. Also, the only machining involved is in the construction of the mount. Clearly, the cantilever beam design provides an acceptable, simple, and inexpensive alternative for misfeed detection.

2. RECOMMENDATIONS

Two tools are offered as a result of this report. First of all, the optimal beam design offers an acceptable detector design which could be incorporated in automatic feed machines. However, in addition to this, further study could be done to arrive at a different optimum design given the model for document/detector impact and the subsequent analysis of the dynamic response of both of the detector systems studied. Predicted responses for similar models could be obtained from the interactive programs included in Appendix O.

LIST OF REFERENCES

LIST OF REFERENCES

1. Bessette, Michael D. "Designing Reliable Paper-Handling Systems," Machine Design, 9 May 1985, p. 55.

2. Deutschman, Aaron D., W. J. Michels, and C. E. Wilson. Machine Design: Theory and Practice. New York: MacMillian Publishing Co., Inc., 1975, pp. 301-326.

3. IBM Manual for the 1255 check reader-sorter, 18 August 1978, p. 9-1.

4. Shaw, Linda and A. J. M. Spencer. "Impulsive Loading of Ideal Fibre-Reinforced Rigid-Plastic Beams." International Journal of Solids and Structures, 13(1977), pp. 823-854.

5. Thomson, William T. Theory of Vibration with Applications. 2nd ed. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1981, p. 3, 323.

6. Timoshenko, S., P. H. Young, and W. Weaver, Jr. Vibration Problems in Engineering. 4th ed. New York: John Wiley and Sons, Inc., 1974, p. 427.

7. Weick, Carl B. Principles of Electronic Technology. Toronto: McGraw-Hill Company of Canada Limited, 1969, p. 312.

APPENDICES

APPENDIX A

ACTUAL DOCUMENT VELOCITY

To determine the actual speed of documents passing through the IBM 1255 reader-sorter used for testing, the angular velocity of one of the drive wheels of known radius (as shown in Figure A.1) was found using a strobe light.

$$w = 480\ rpm \tag{A.1}$$

$$r = 1.5\ in \tag{A.2}$$

With these values found, the document speed is calculated.

$$v_{document} = wr = \left(925\ \frac{rev}{min}\right)\left(2\pi\ \frac{rad}{rev}\right)\left(\frac{min}{60\ sec}\right)\left(1.5\ in\right) \tag{A.3}$$

$$v_{document} = 145\ \frac{in}{sec} \tag{A.4}$$

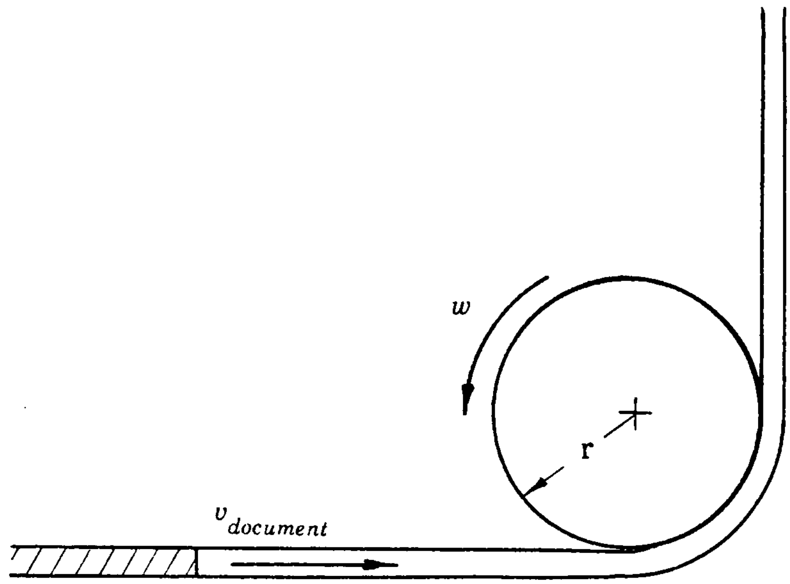


Figure A.1. Drive wheel/document system.

APPENDIX B

MAXIMUM ALLOWABLE FORCE ON DOCUMENT

One of the constraints in implementing a detector device is that the documents must not be mutilated or slowed down. To perform an analysis of the detector, a maximum allowable force to satisfy these constraints must be experimentally determined. The experimental apparatus used to determine this value is shown in Figure B.1. The device shown consists of two thin shim steel beams mounted to a block of wood. The lower beam is deflected against the checks in the transport pathway with the upper beam serving as a reference to give a value of the distance of deflection of the lower beam.

The region of deflection is depicted in Figure B.2. For different values of deflection, the load on the check can be determined using the following relationships.

$$P = \frac{3EI\delta}{L^3} \tag{B.1}$$

where: $E = 30 \times 10^6$ psi for shim steel

$I = \frac{wb^3}{12} = \frac{(0.71 \text{ in.})(0.01 \text{ in.})^3}{12} = 59.1 \times 10^{-9} \text{in}^4$

w = width of beam = 0.71 in.

b = thickness of beam = 0.01 in.

L = 1.22 in.

w = width of beam = 0.71 in.

b = thickness of beam = 0.01 in.

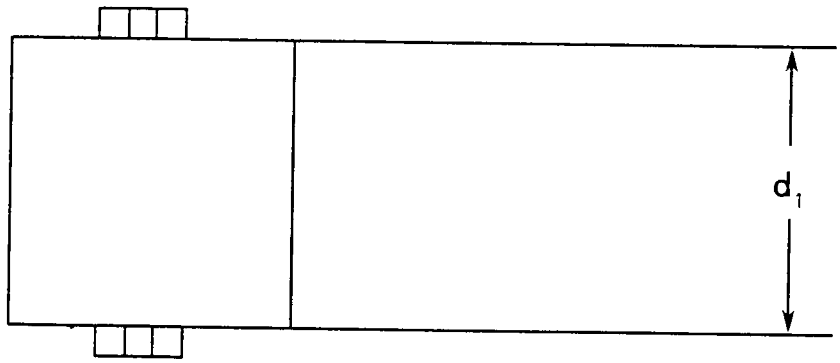


Figure B.1. Device for maximum force determination.

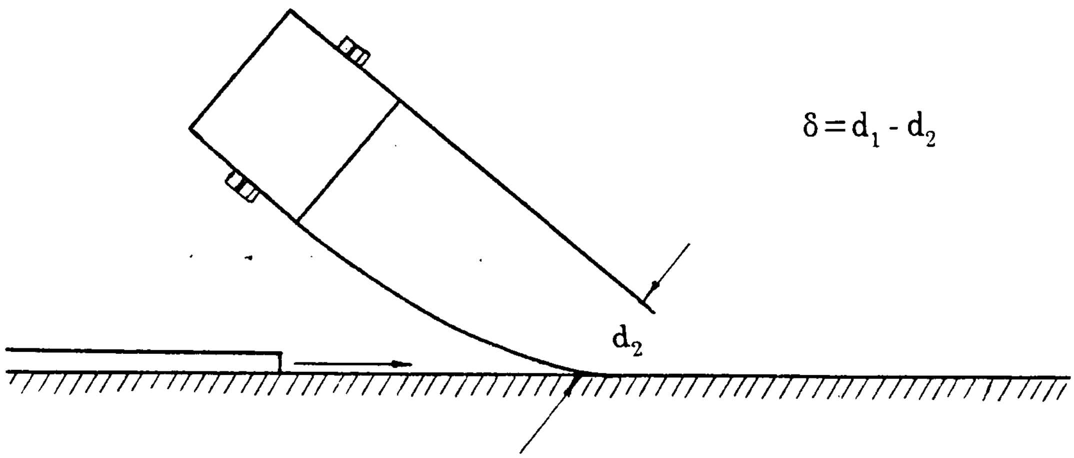


Figure B.2. Description of deflection.

Table B.1 gives the result of the force test. The experimentally-found maximum force is 0.46 lb.

Table B.1 Results of force testing.

Deflection (in)	Force (lb)	Comments
0.5	1.44	severe damange to checks
0.4	1.15	some slowing / wrinkling
0.3	0.86	some slowing / wrinkling
≤0.16	0.46	no noticeable problems

APPENDIX C

MOMENT ANALYSIS OF LEVER ARM/DOCUMENT SYSTEM

1. INTRODUCTION

The system of interest was modeled as a spring and damper affixed to a rigid document of constant velocity striking a rigid arm at some angle, θ. This system is depicted in Figure C.1.

To determine the effect of the document impact, a moment analysis was conducted about point 0.

$$I\ddot{\theta} = \sum T_o = k[v_c t - \Delta]\, L \sin\theta_{str} + c[v_c - \dot{\Delta}]\, L \sin\theta_{str} - T_{fr} - W_{arm}(L - \overline{Y}) \cos\theta_{str} \quad \text{(C.1)}$$

where:

k and c are the spring constant and damping coefficient, respectively, associated with the document.

v_c is the velocity of the document.

t is time.

Δ is the relative displacement of the arm away from the document.

L is the length of the arm.

θ_{str} is the striking angle of the document with respect to the arm.

T_{fr} is the frictional torque (37.5×10^{-6} in-lb).

W_{arm} is the weight of the arm.

Y is the center of gravity of the arm.

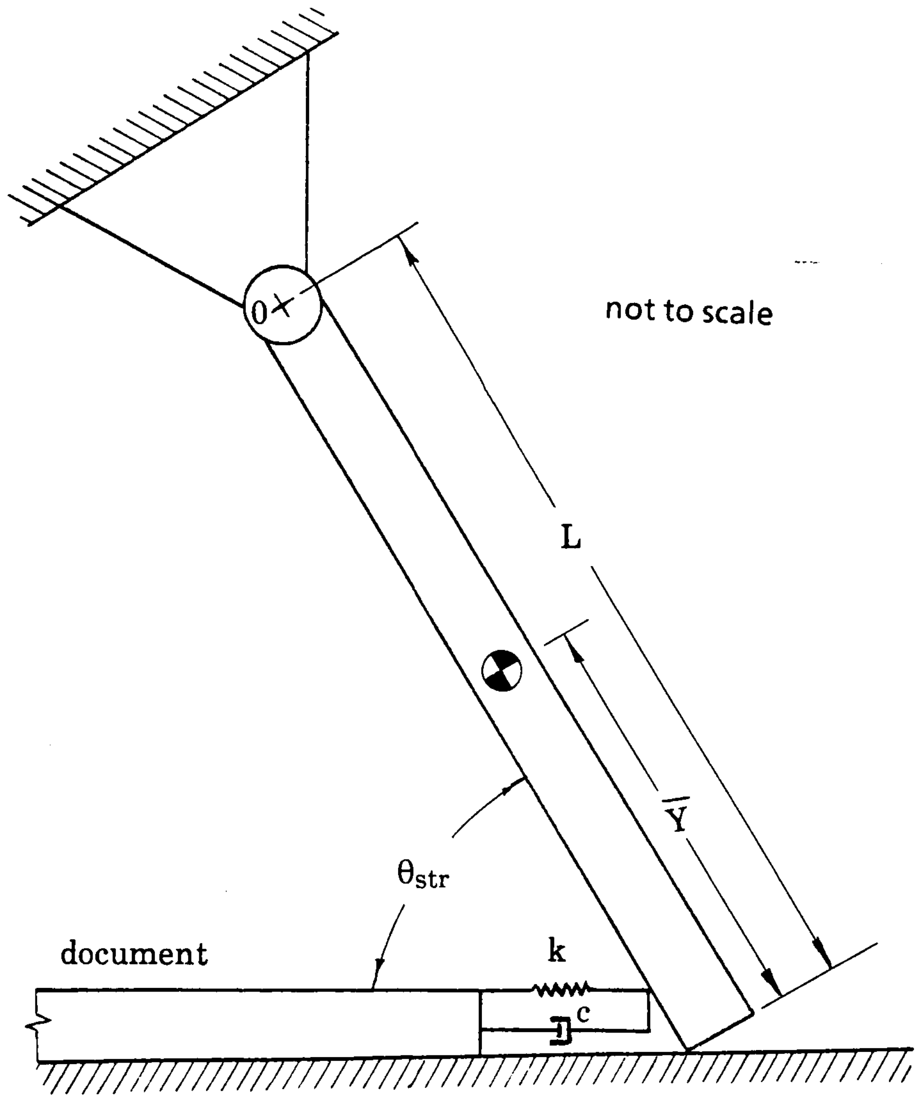


Figure C.1. Lever arm/document system.

2. MOTION OF ARM RELATIVE TO DOCUMENT

The diagram used for the solution of Δ is shown in Figure C.2.

From the figure:

$$tan\,\theta_{str} = \frac{Z}{X_1} \tag{C.2}$$

$$tan\,(\theta_{str} - \theta) = \frac{Z}{X_2} \tag{C.3}$$

$$\Delta = X_2 - X_1 = Z\left[\frac{1}{tan\,(\theta_{str} - \theta)} - \frac{1}{tan\,(\theta_{str})}\right] \tag{C.4}$$

$$\frac{\partial\Delta}{\partial\theta} = Z\left[\frac{1}{sin^2(\theta_{str} - \theta)}\right] \tag{C.5}$$

$$\Delta = \frac{\partial\Delta}{\partial\theta}\cdot\ \theta = Z\theta\left[\frac{1}{sin^2(\theta_{str} - \theta)}\right] \tag{C.6}$$

For $\theta_{str} >> \theta$:

$$\Delta = \frac{Z\theta}{sin^2(\theta_{str})} \tag{C.7}$$

$$sin\,\theta_{str} = \frac{Z + T_c}{L} = \frac{\dfrac{\Delta sin^2\theta_{str}}{\theta} + T_c}{L} = \frac{\Delta sin^2\theta_{str}}{\theta L} + \frac{T_c}{L} \tag{C.8}$$

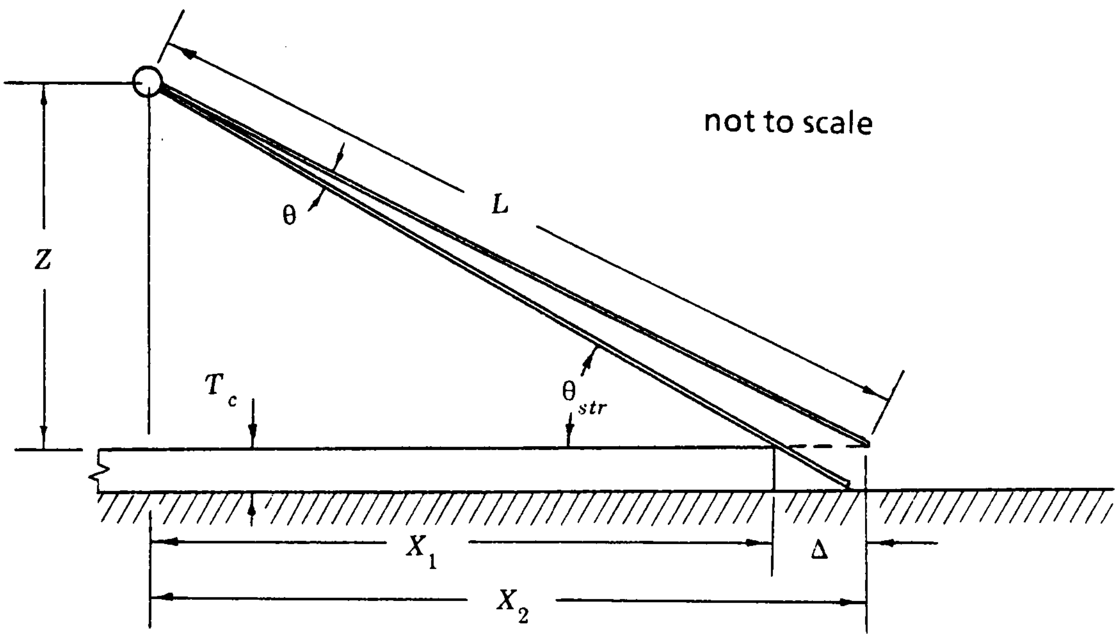


Figure C.2. Geometry of document/detector impact.

$$\Delta = \frac{\theta L}{\sin\theta_{str}} - \frac{T_c\theta}{\sin^2\theta_{str}} \tag{C.9}$$

Solving for $\dot{\Delta}$:

$$\Delta = X_2 - X_1 = Z\left[\frac{1}{\tan(\theta_{str} - \theta)} - \frac{1}{\tan(\theta_{str})}\right] \tag{C.4}$$

$$\dot{\Delta} = \frac{\partial\Delta}{\partial\theta}\frac{\partial\theta}{\partial t} = Z\left[\frac{1}{\sin^2(\theta_{str} - \theta)}\right]\dot{\theta} \tag{C.10}$$

For $\theta_{str} >> \theta$:

$$\dot{\Delta} = \frac{Z\dot{\theta}}{\sin^2\theta_{str}} \tag{C.11}$$

$$\sin\theta_{str} = \frac{Z + T_c}{L} + \frac{\dot{\Delta}\sin^2\theta_{str}}{\dot{\theta}L} + \frac{T_c}{L} \tag{C.12}$$

$$\dot{\Delta} = \frac{\dot{\theta}L}{\sin\theta_{str}} - \frac{\dot{\theta}T_c}{\sin^2\theta_{str}} \tag{C.13}$$

3. SOLUTION FOR θ and $\dot{\theta}$

Substituting the values for $\dot{\Delta}$ and Δ from Equations C.7 and C.13 into Equation C.1:

$$I\ddot{\theta} = k\left(v_c t - \theta\left(\frac{L}{sin\theta_{str}} - \frac{T_c}{sin^2\theta_{str}}\right)\right)L sin\,\theta_{str}$$

$$+ c\left(v_c - \dot{\theta}\left(\frac{L}{sin\theta_{str}} - \frac{T_c}{sin^2\theta_{str}}\right)\right)L\, sin\theta_{str}$$

$$- T_{fr} - W_{arm}(L - \overline{Y}\, cos\,\theta_{str}) \qquad \text{(C.14)}$$

Setting up in terms of derivatives of θ:

$$I\ddot{\theta} + \left(cL^2 - \frac{cT_c L}{sin\,\theta_{str}}\right)\dot{\theta} + \left(kL^2 - \frac{kT_c L}{sin\,\theta_{str}}\right)\theta =$$

$$(kv_c L\, sin\,\theta_{str})\, t + \left(cv_c L\, sin\,\theta_{str} - T_{fr} - W_{arm}(L - \overline{Y})\, cos\,\theta_{str}\right) \qquad \text{(C.15)}$$

Substituting variables, let

$$C = cL^2 - \frac{cT_c L}{sin\,\theta_{str}} \qquad \text{(C.16)}$$

$$K = kL^2 - \frac{kT_c L}{sin\,\theta_{str}} \qquad \text{(C.17)}$$

$$c_1 = kv_c L\, sin\,\theta_{str} \qquad \text{(C.18)}$$

$$c_2 = cV_c L \sin\theta_{str} - T_{fr} - W_{arm}(L - \overline{Y})\cos\theta_{str} \tag{C.19}$$

This gives the following equation.

$$I\ddot{\theta} + C\dot{\theta} + K\theta = c_1 t + c_2 \tag{C.20}$$

There are three possible general solutions for this equation depending on the value of the damping ratio, ζ, ($\zeta < 1, \zeta > 1, \zeta = 1$), where

$$\zeta = \frac{C}{C_c} = \frac{C}{2\sqrt{KI}} \tag{C.21}$$

For this analysis, ζ will always be less than 1.0 (oscillatory motion). For this case, the solution would take on the following form.

$$\theta = e^{-c_3 t}(A \sin c_4 t + B \cos c_4 t) + A_o t + A_1 \tag{C.22}$$

$$\dot{\theta} = e^{-c_3 t}(A c_4 \cos c_4 t - B c_4 \sin c_4 t) - c_3 e^{-c_3 t}(A \sin c_4 t + B \cos c_4 t) + A_o \tag{C.23}$$

where:

$$c_3 = \frac{C}{2I} \tag{C.24}$$

$$c_4 = \sqrt{\frac{K}{I} - (c_3)^2} \tag{C.25}$$

$$A_0 = \frac{c_1}{K} \tag{C.26}$$

$$A_1 = \left(c_2 - C\left(\frac{c_1}{K}\right)\right) / K \tag{C.27}$$

$$A = \frac{-A_o - c_3 A_1 + c_3 \theta(0) + \dot{\theta}(0)}{c_4} \tag{C.28}$$

$$B = -A_1 + \theta(0) \tag{C.29}$$

APPENDIX D

DETERMINATION OF INITIAL ANGULAR VELOCITY OF LEVER ARM

The lever arm is shown in Figure D.1. The document strikes the lever arm with some velocity, V_c, causing the arm to rise h_{max}. The initial angular velocity of the arm is found as follows.

Let subscript 1 represent the energy of the system just after the document strikes the arm. The subscript 2 represents the energy of the system when the arm reaches its maximum height.

$$(ENERGY)_1 = (KE)_1 + (PE)_1 = \tfrac{1}{2} I \dot{\theta}_i^2 + 0 \qquad \text{(D.1)}$$

$$(ENERGY)_2 = (KE)_2 + (PE)_2 = 0 + mg\Delta h_{cg} \qquad \text{(D.2)}$$

$$(ENERGY)_1 - (ENERGY)_2 = LOSSES\ (FRICTIONAL) \qquad \text{(D.3)}$$

To determine the frictional losses in the system, the lever arm was removed from the transport region. The arm was offset from its position vertically at rest by some angle, θ_i (see Figure D.2). The arm was released from this position and allowed to swing until θ_i was decreased by a factor of 2 (due to frictional losses). The plot of this response is given in Figure D.3.

The energy of the system is described as follows.

$$(ENERGY)_i - (ENERGY)_f = LOSSES\ (FRICTIONAL) \qquad \text{(D.4)}$$

$$(ENERGY)_i = mg\,\overline{Y}\,(1 - \cos\theta_i) \qquad \text{(D.5)}$$

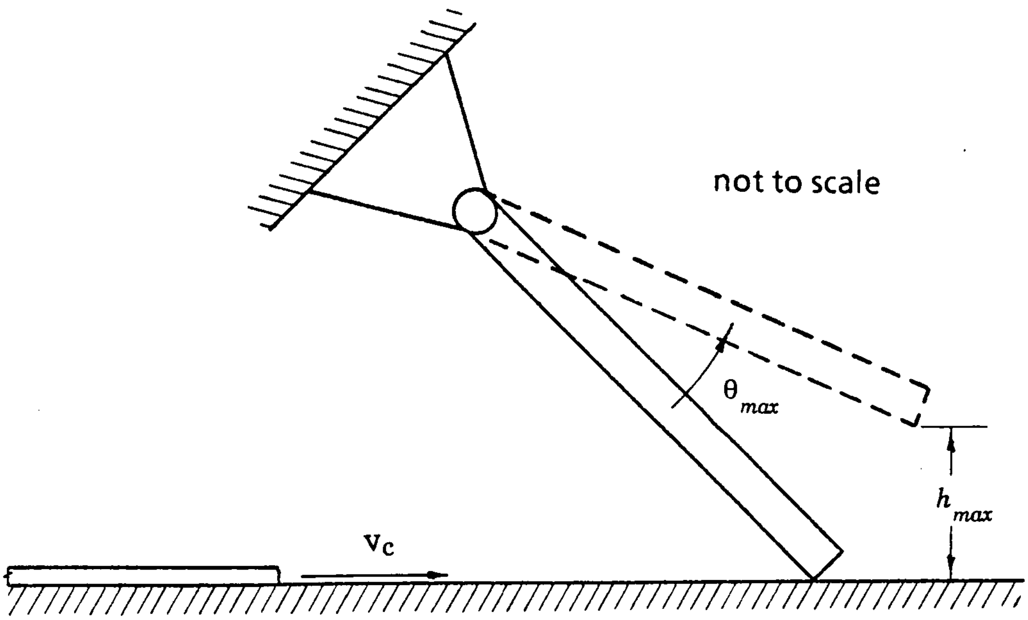


Figure D.1. Lever arm system.

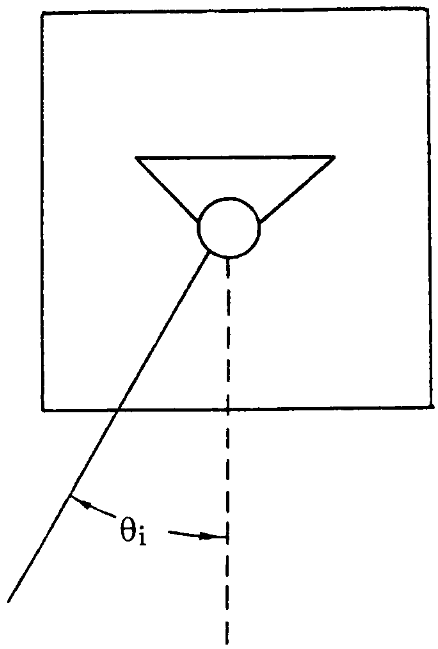


Figure D.2. Determination of the frictional losses.

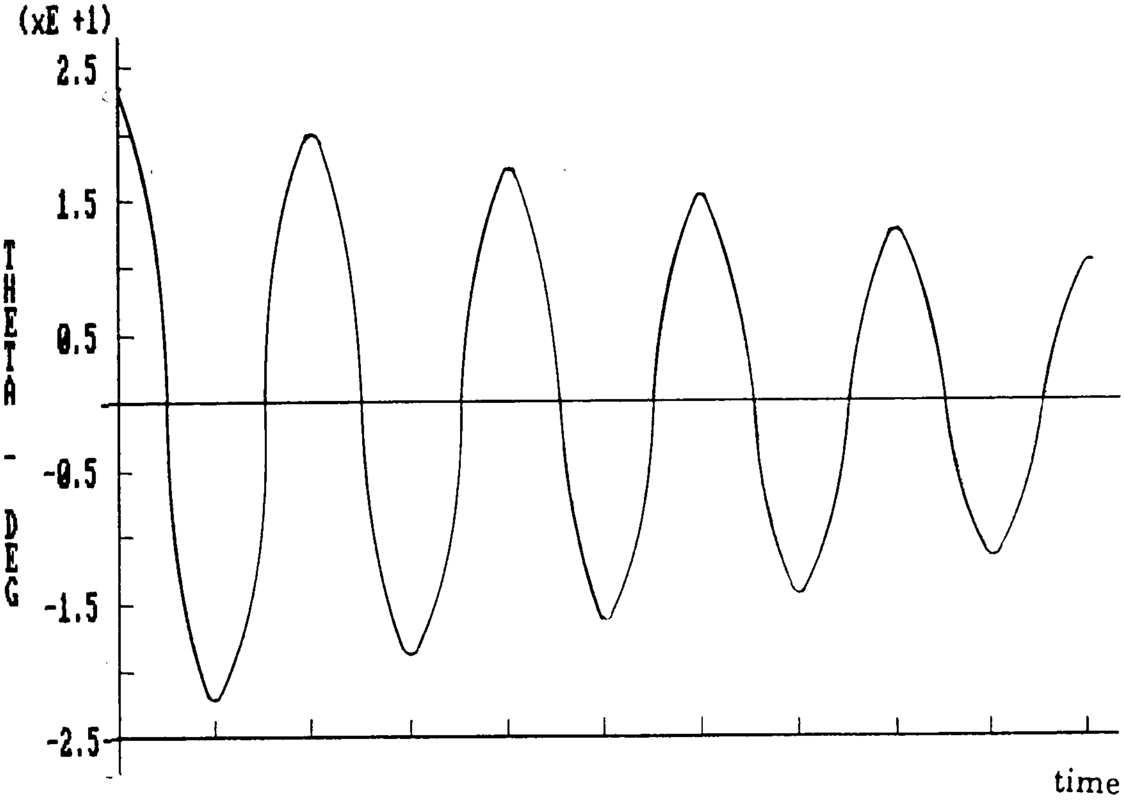


Figure D.3. Effect of friction on arm response.

$$(ENERGY)_f = mg\,\overline{Y}\,(1 - \cos\theta_f) \tag{D.6}$$

$$LOSSES = T_{fr}\,\theta \tag{D.7}$$

where: θ_i is the initial offset angle from the vertical.

θ_f is the final offset angle from the vertical.

T_{fr} is the frictional torque.

θ is the total angular displacement the arm goes through in traveling from θ_i to θ_f.

Plugging Equations D.5, D.6, D.7 into Equation D.4 and substituting numerical values:

$$(0.0034\ lb)(1.02\ in)[\cos(11^\circ) - \cos(24^\circ)] = T_{fr}(6.3\ rad) \tag{D.8}$$

$$T_{fr} = 37.5 \times 10^{-6}\ in - lb \tag{D.9}$$

The equation of motion can now be described. Substituting Equations D.7, D.1, D.2 into Equation D.3:

$$\tfrac{1}{2} I \dot{\theta}_i^2 = W\,\Delta h_{cg} - T_{fr}\,\theta_{max} \tag{D.10}$$

where: $$\Delta h_{cg} = (L - \overline{Y})\left(\frac{h_{max}}{L}\right) \tag{D.11}$$

$$\theta_{max} = sin^{-1}\left(\frac{h_{max}}{L} - sin\,\theta\right) + \theta \tag{D.12}$$

Solving for $\dot{\theta}_i$:

$$\dot{\theta}_i = \left[\frac{2Wh_{max}}{IL}(L - \overline{Y}) - \frac{2T_{fr}}{I}\left(sin^{-1}\left(\frac{h_{max}}{L} - sin\,\theta\right) + \theta\right)\right]^{\frac{1}{2}} \tag{D.13}$$

To simplify the expression for $\dot{\theta}_i$, the frictional contribution was found in terms of the rest of the expression. Friction at the pivot was found to reduce $\dot{\theta}_i^2$ by approximately 1.5%.

$$\dot{\theta}_i = \left[.985\,\frac{2Wh_{max}}{IL}(L - \overline{Y})\right]^{\frac{1}{2}} \tag{D.14}$$

This value of $\dot{\theta}_i$ is the experimental value found by substituting the numerical values for the physical parameters and determining h_{max} experimentally for different values of θ. The maximum height was found using an eddy current probe to record the upward displacement of a point near the pivot on the rigid arm on an oscilloscope. To determine the distance that the end of the beam raised, the beam was moved by hand so that the same oscilloscope response was observed. This height was then recorded from the oscilloscope.

APPENDIX E

PLOTS OF $\dot{\theta}_i$ vs k

1. INTRODUCTION

The following plots compare the $\dot{\theta}_i$ vs k relationship determined from the computer analysis to experimentally-determined values of the maximum and average initial angular velocity to provide an accurate estimate for the spring constants associated with three different document types. The following parameters are varied on the plots: document type, striking angle of document, and moment of inertia of arm. Table E.1 gives a complete description of the tests run. The striking angle is given first. Then the maximum and average values for $\dot{\theta}_i$ are listed. The fifth column describes at what hole weight is added. This yields a corresponding moment of inertia. The last column is the type of document.

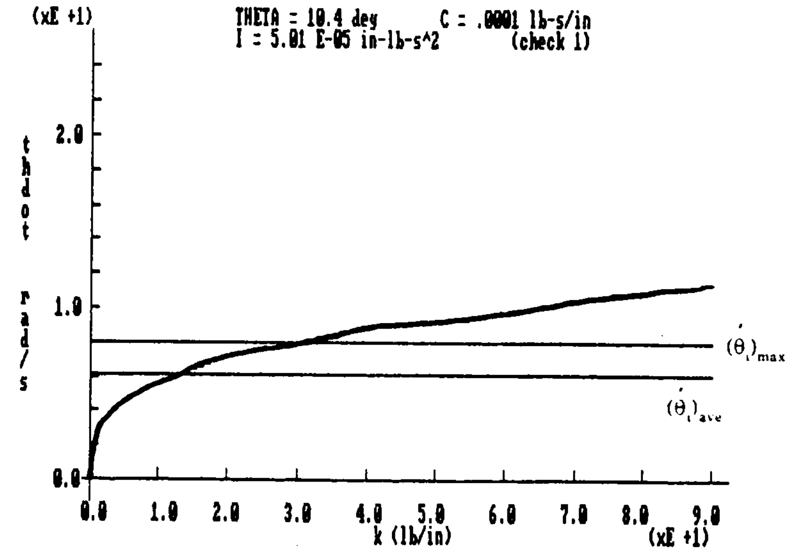
In the following plots, the two horizontal lines correspond to the experimentally-determined maximum and average values of the initial angular velocity. The curve is the computer-generated plot of $\dot{\theta}_i$ vs. k.

2. STANDARD CHECKS

The first document type tested was a standard check (thickness = .004 in.). Figure E.1 shows the results of these tests.

Table E.1. Description of experimental tests.

STR ANGLE (deg)	THDOT AVE (rad/s)	THDOT MAX (rad/s)	Ix10^5 (in-lb-s^2)	ADDWT?	TYPE
10.4	6.2	8.0	5.01	1	CH
10.4	6.0	7.4	5.01	1	CH
10.4	11.6	12.5	1.10	N	CH
10.4	11.7	12.6	1.10	N	CH
12.5	13.1	14.3	1.10	N	CH
12.5	12.0	14.3	1.10	N	CH
12.5	8.4	9.6	8.95	2	CH
12.5	9.8	10.6	8.95	2	CH
19.5	15.3	17.1	1.10	N	CH
19.5	16.1	17.9	1.10	N	CH
19.5	9.3	10.5	8.95	2	CH
19.5	9.9	10.5	8.95	2	CH
12.5	8.3	8.5	8.95	2	WS
12.5	8.5	8.8	8.95	2	WS
12.5	14.6	16.0	1.10	N	WS
12.5	14.3	15.2	1.10	N	WS
19.5	16.7	18.0	1.10	N	WS
19.5	16.1	17.6	1.10	N	WS
19.5	9.3	9.8	8.95	2	WS
19.5	9.3	9.9	8.95	2	WS
10.4	6.6	8.0	5.01	1	WS
17.5	16.4	17.8	1.10	N	WS
17.5	15.6	16.4	1.10	N	WS
15.0	13.3	14.8	1.10	N	WS
15.0	12.9	14.5	1.10	N	WS
17.5	15.1	16.3	1.10	N	CH
17.5	15.5	17.2	1.10	N	CH
15.0	12.8	14.8	1.10	N	CH
15.0	11.3	12.9	1.10	N	CH
for the above documents thickness = .004 in.					
for the documents below thickness = .0065 in.					
10.4	9.2	10.2	5.01	1	IBM
10.4	9.8	10.8	5.01	1	IBM
10.4	10.0	10.8	5.01	1	IBM
15.4	18.1	19.9	1.10	N	IBM
19.0	9.8	10.7	8.95	2	IBM
19.0	9.5	11.1	8.95	2	IBM
12.5	10.2	10.9	8.95	2	IBM
12.5	9.4	10.5	8.95	2	IBM
17.5	18.4	21.2	1.10	N	IBM
17.5	17.3	20.3	1.10	N	IBM



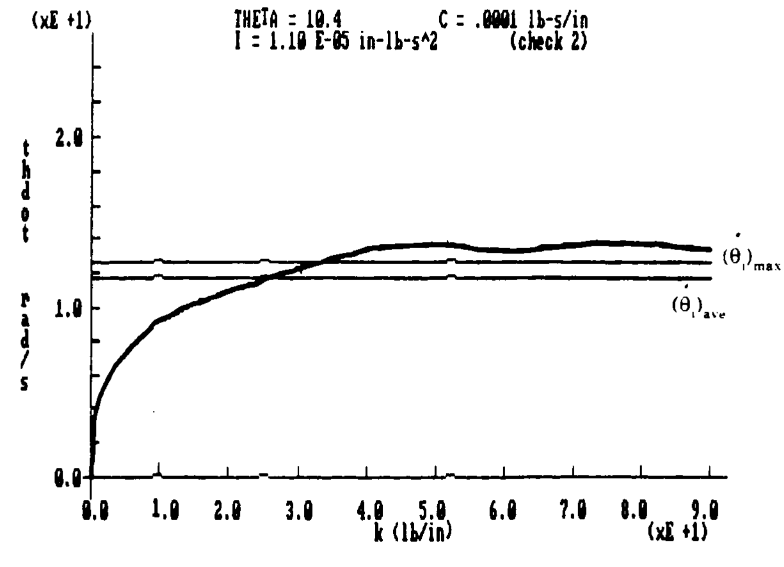
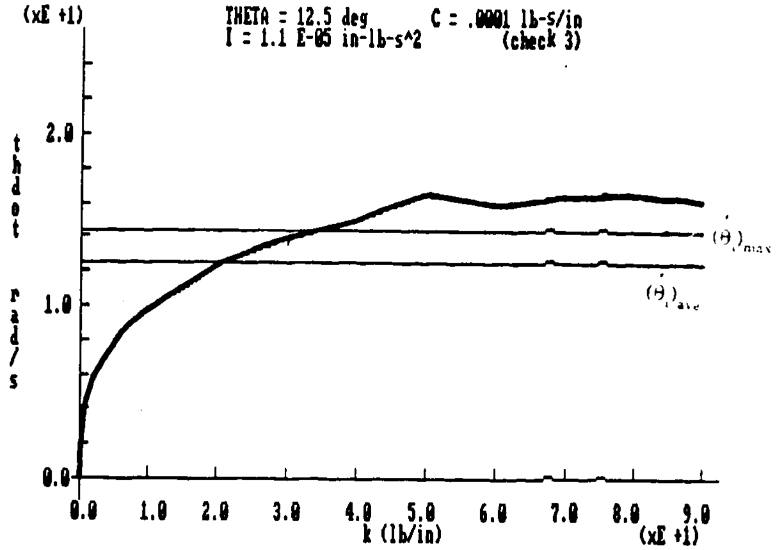


Figure E.1. Response of standard checks.



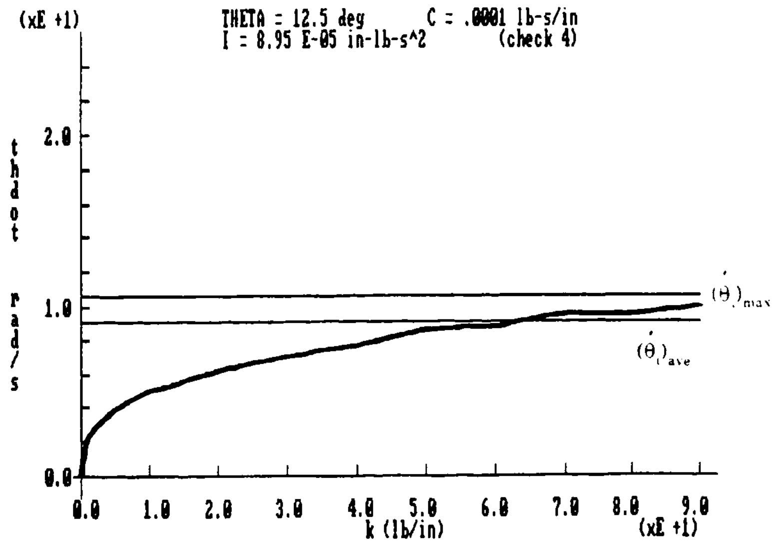
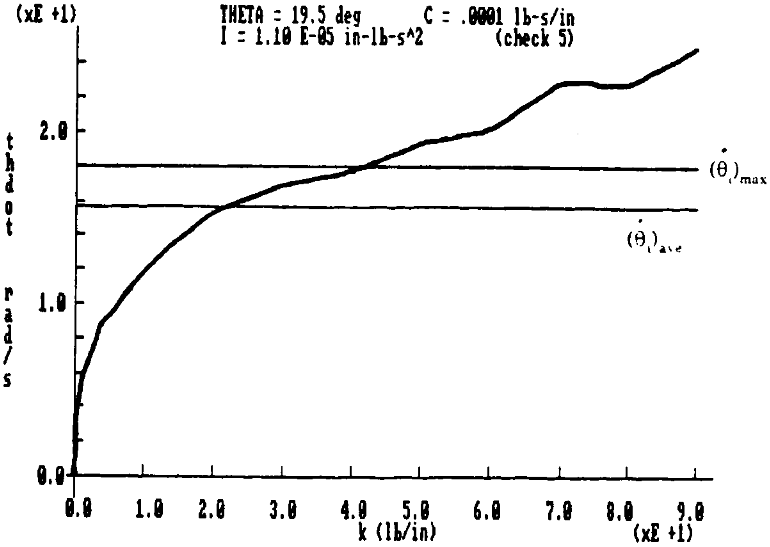


Figure E.1 (continued).



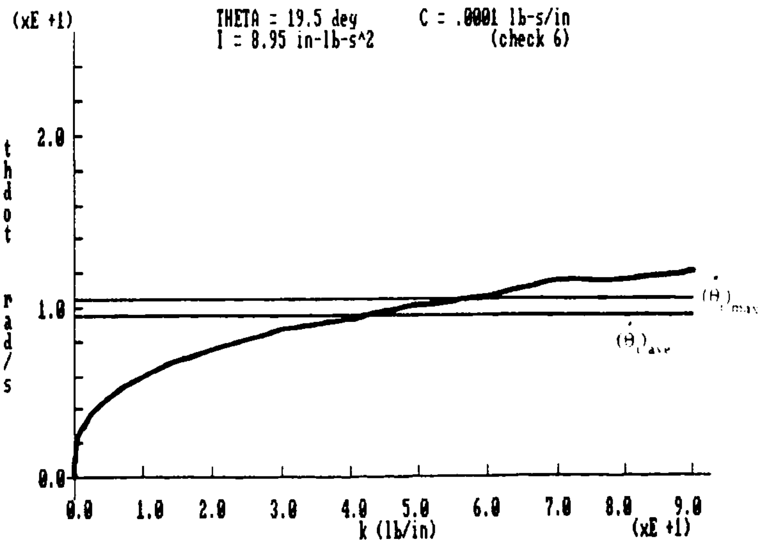
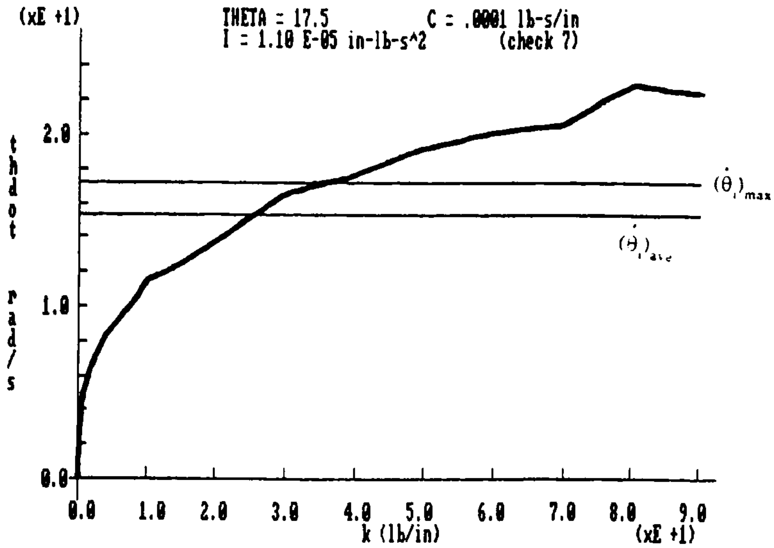


Figure E.1 (continued).



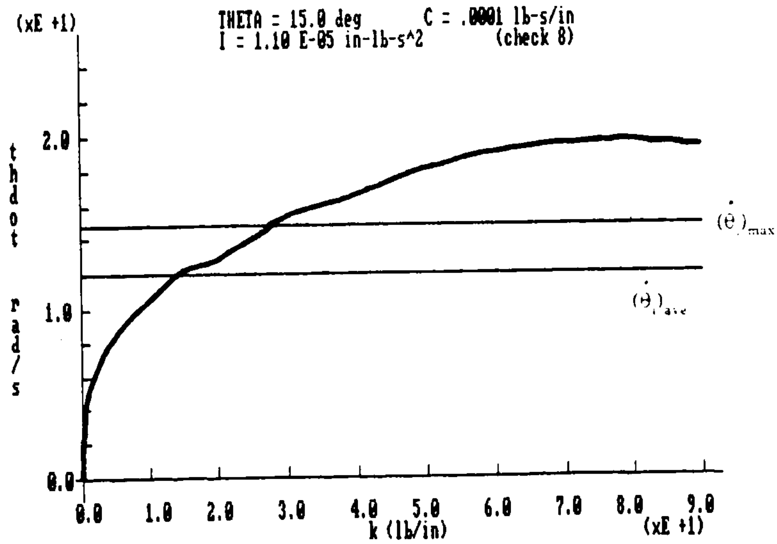
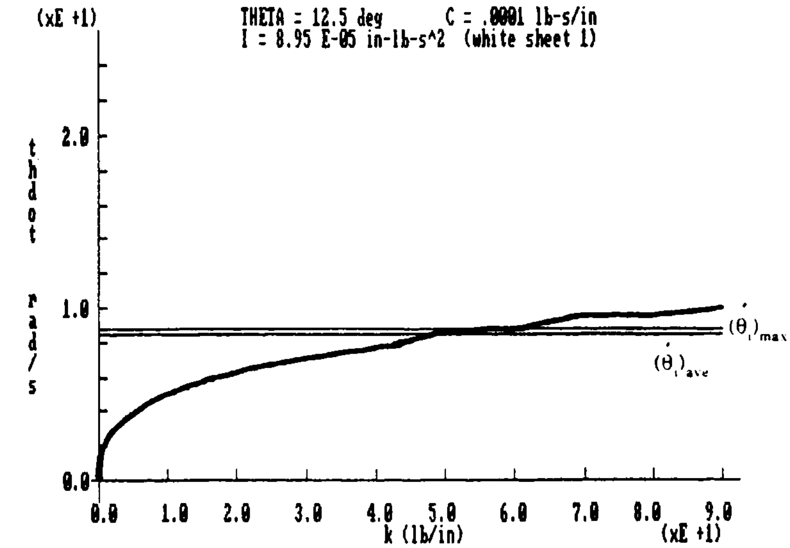


Figure E.1 (continued).

3. WHITE SHEETS

The next document tested was a lightweight white sheet (thickness = .004 in.) . Figure E.2 shows the results of these tests.



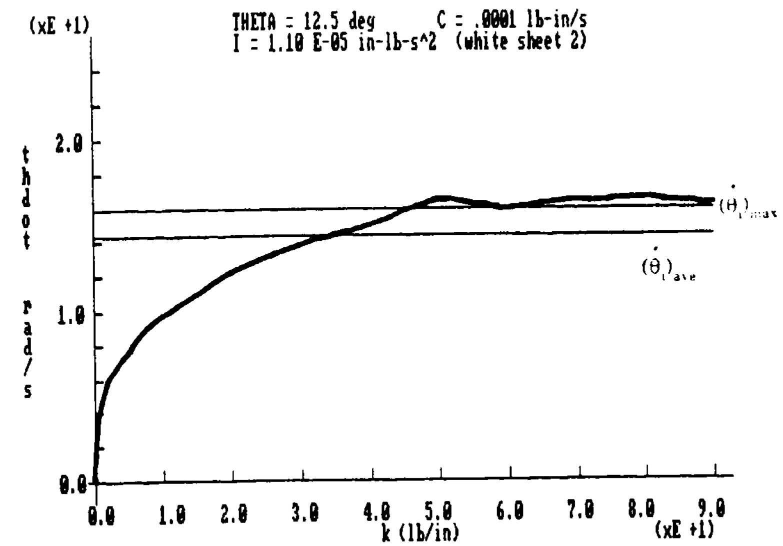
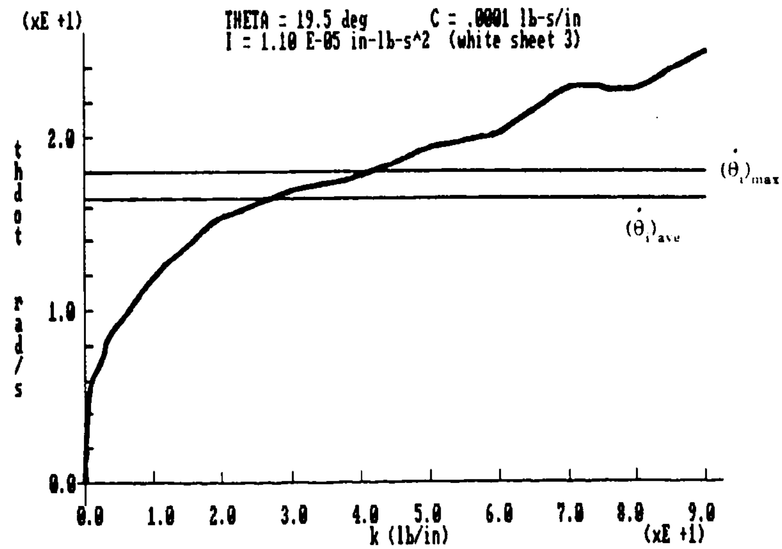


Figure E.2. Response of lightweight white sheets.



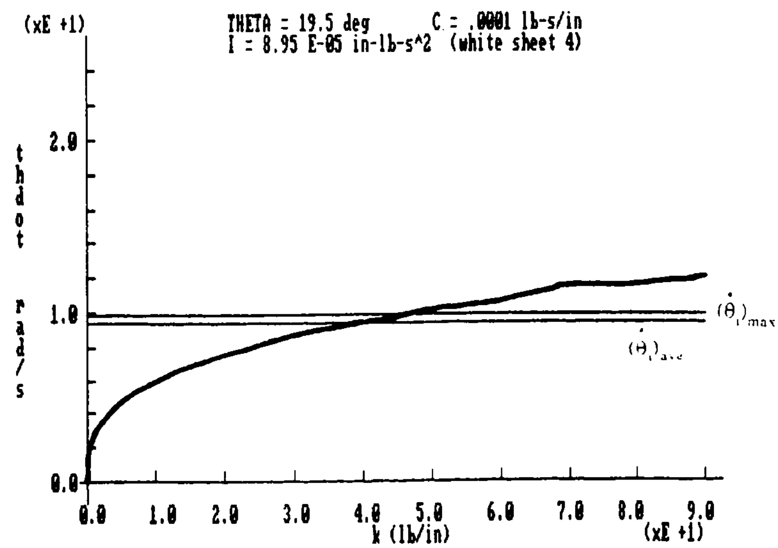
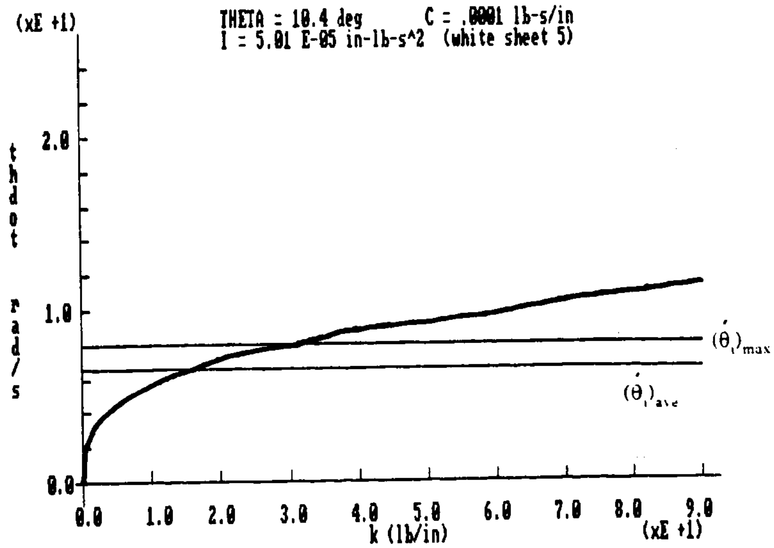


Figure E.2 (continued).



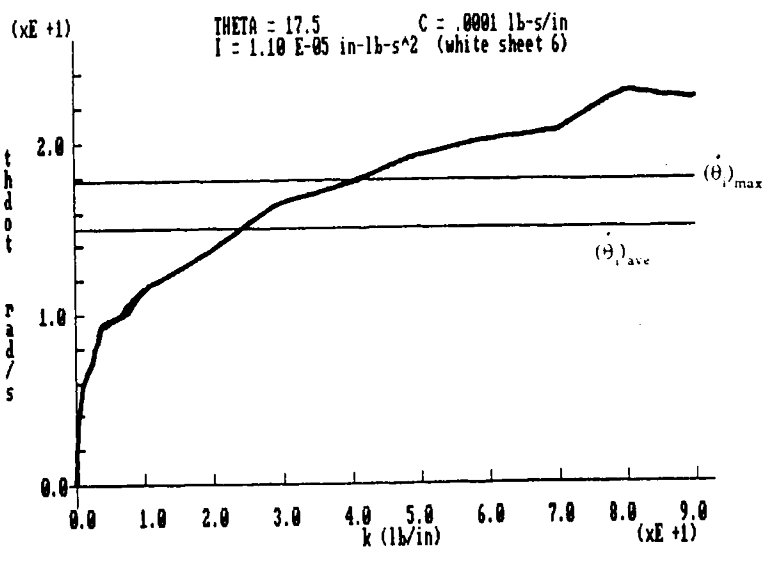


Figure E.2 (continued).

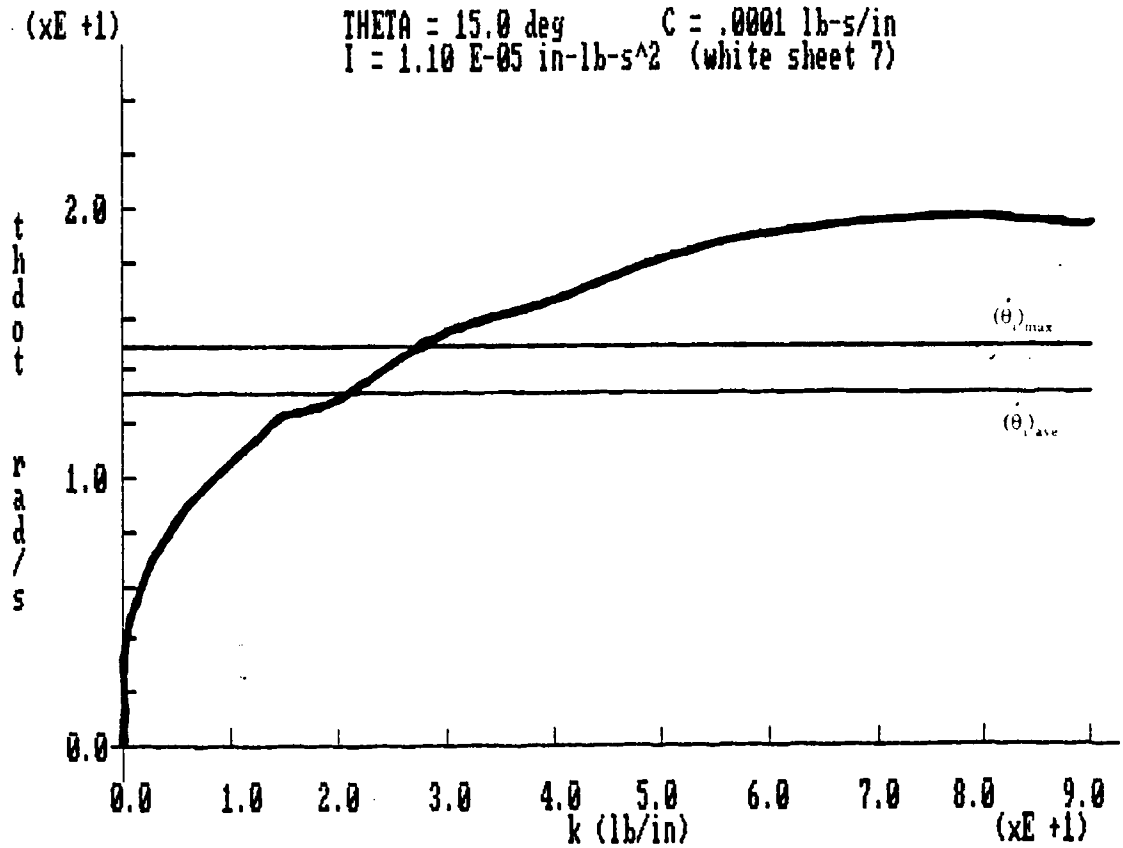


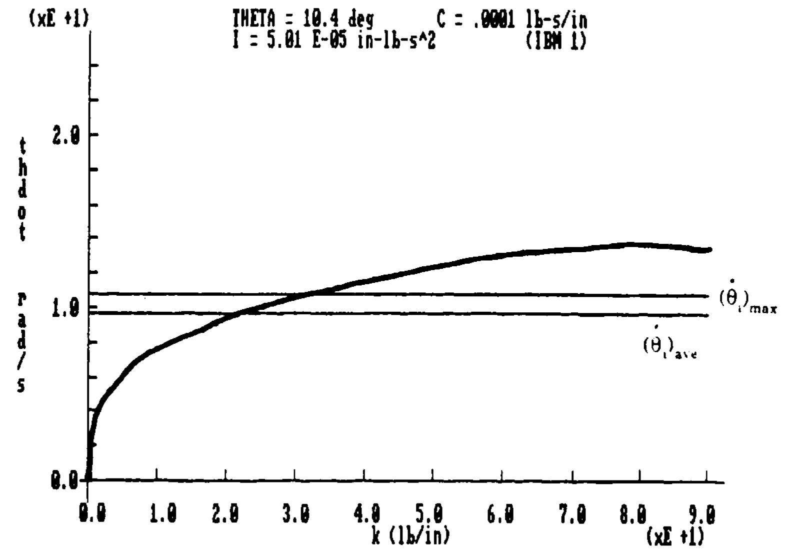
Figure E.2 (continued).

4. IBM CARDS

Finally, several IBM cards were tested (thickness = .0065 in.). The results of these tests are displayed in Figure E.3.

5. RESULTS

The best value for the spring constant associated with all three document types was found to be approximately equal to 30 lb/in. This value will be used in subsequent analysis.



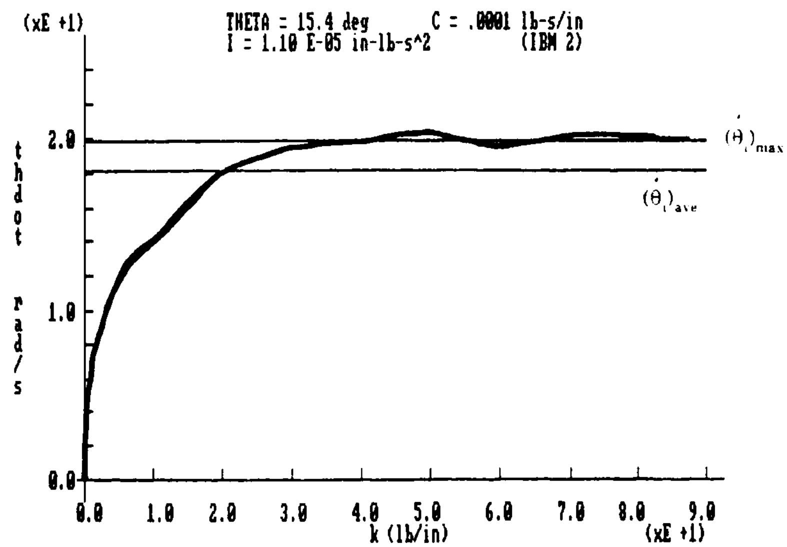
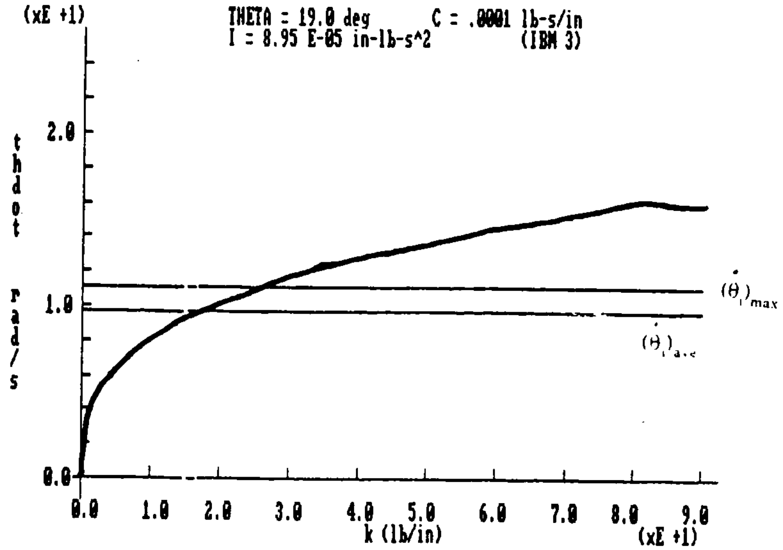


Figure E.3. Response of IBM cards.



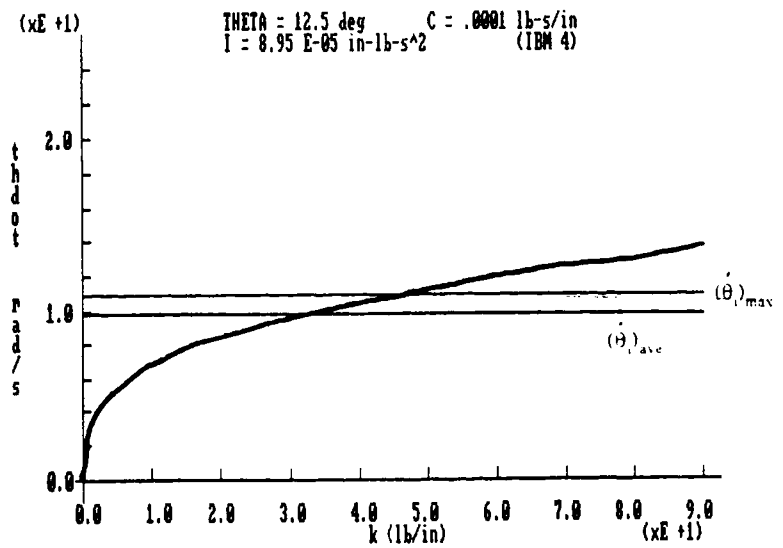


Figure E.3 (continued).

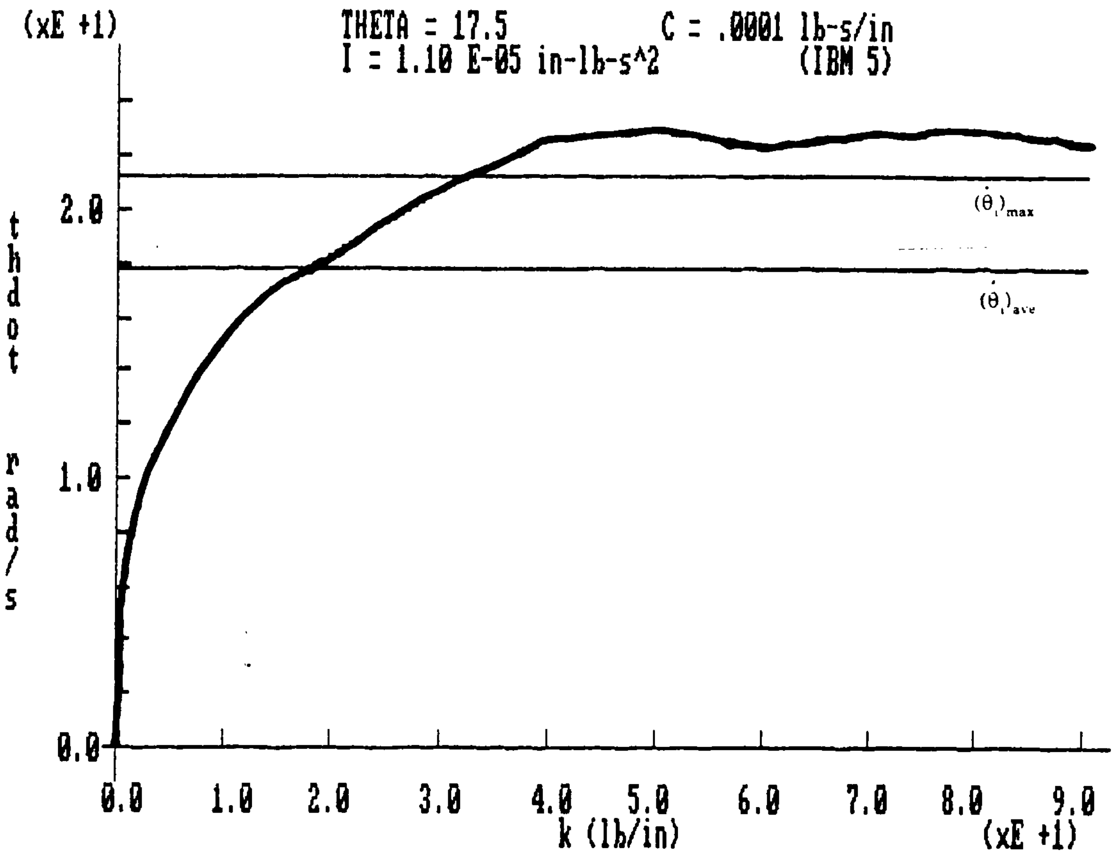


Figure E.3 (continued).

APPENDIX F

DISCRETE MASS SYSTEM

1. INTRODUCTION

Figure F.1 depicts the system to be analyzed. Four parameters associated with each discrete mass point will be expressed: the distance from the imbedded end, x, the length of beam lumped at a mass point, Δx, the mass associated with each discrete mass, m, and the mass moment of inertia of that section, J.

2. ANALYSIS

$$L_t = total\ length\ of\ beam \tag{F.1}$$

$$L_c = length\ of\ beam\ to\ transport\ base \tag{F.2}$$

Therefore, for n discrete masses beyond the imbedded end:

$$Let\ A = L_c\,/\,(2n) \tag{F.3}$$

$$x_o = 0 \tag{F.4}$$

$$\Delta x_o = A \tag{F.5}$$

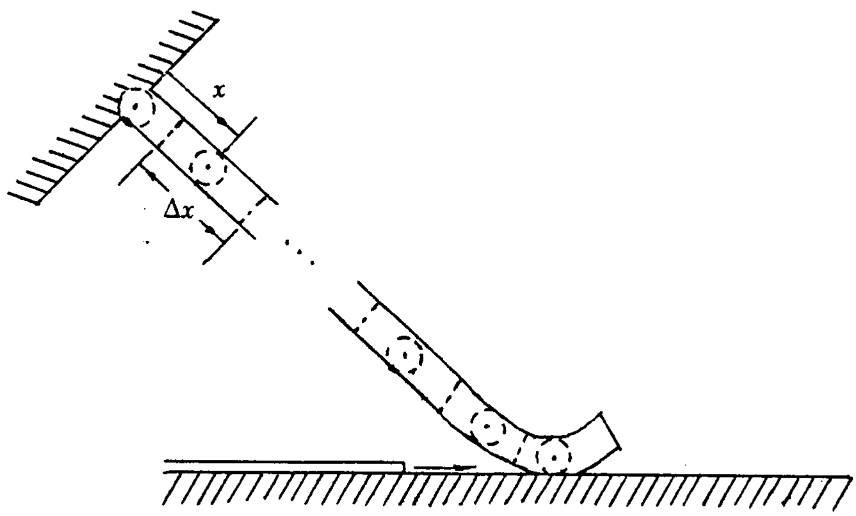


Figure F.1. Discrete mass system

$$x_n = L_c \tag{F.6}$$

$$\Delta x_n = A + (L_t - L_c) \tag{F.7}$$

For 0 < i < n:

$$x_i = 2iA \tag{F.8}$$

$$\Delta x_i = 2A \tag{F.9}$$

$$M = total\, mass\, of\, beam \tag{F.10}$$

$$\rho = M/L_t \tag{F.11}$$

For all i:

$$m_i = \rho \Delta x_i \tag{F.12}$$

$$T = thickness\, of\, beam \tag{F.13}$$

$$J_i = m_i (T^2 + x_i^2) / 12 \tag{F.14}$$

APPENDIX G

TRANSFER MATRIX ANALYSIS

Upon impact by a document, the beam will deflect transversely and rotate. Isolating an interior section of the beam, expressions can be found for this deflection and rotation. Figure G.1 shows this isolated section, where the quantities just to the left and right of the mass are denoted by superscripts L and R, respectively.

Considering the massless beam section:

$$y_{i+1}^{L} = y_i^R + \theta_i^R l_i + M_{i+1}^{L}\left(\frac{l_i^2}{2EI}\right) + V_{i+1}^{L}\left(\frac{l_i^3}{3EI}\right) \tag{G.1}$$

$$\theta_{i+1}^{L} = \theta_i^R + M_{i+1}^{L}\left(\frac{l_i}{EI}\right) + V_{i+1}^{L}\left(\frac{l_i^2}{2EI}\right) \tag{G.2}$$

$$V_{i+1}^{L} = V_i^R \tag{G.3}$$

$$M_{i+1}^{L} = -M_i^R - V_i^R l_i \tag{G.4}$$

Solving for V and M:

$$V_i^R = V_{i+1}^{L} = \left(\frac{12EI}{l_i^3}\right)\left(y_{i+1}^{L} - y_i^R\right) - \left(\frac{6EI}{l_i^2}\right)\left(\theta_{i+1}^{L} + \theta_i^R\right) \tag{G.5}$$

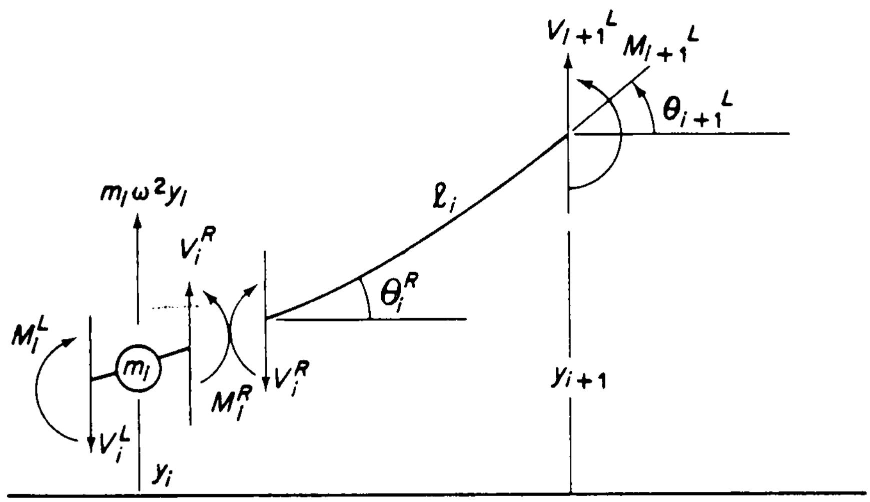


Figure G.1. Beam section (i[th] section) for analysis.

Source: William T. Thomson, Theory of Vibration with Applications, 2nd ed. (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1981), p. 323.

$$M_i^R = -\left(\frac{6EI}{l_i^2}\right)\left(y_{i+1}^L - y_i^R\right) + \left(\frac{2EI}{l_i}\right)\left(\theta_{i+1}^L + 2\theta_i^R\right) \tag{G.6}$$

$$M_{i+1}^L = -\left(\frac{6EI}{l_i^2}\right)\left(y_{i+1}^L - y_i^R\right) + \left(\frac{2EI}{l_i}\right)\left(2\theta_{i+1}^L + \theta_i^R\right) \tag{G.7}$$

The following equations may be written by considering general discrete mass points on the beam.

$$\sum F_i = m_i \ddot{y}_i = V_i^R - V_i^L \tag{G.8}$$

$$\sum M_i = J_i \ddot{\theta}_i = M_i^R - M_i^L \tag{G.9}$$

$$\theta_i^R = \theta_i^L = \theta_i \tag{G.10}$$

$$y_i^R = y_i^L = y_i \tag{G.11}$$

Conditions on the system are as follows.

$$y_o = \dot{y}_o = \theta_o = \dot{\theta}_o = 0 \tag{G.12}$$

$$M_n^R = V_n^R = 0 \tag{G.13}$$

$$\sum F_n = m_n \ddot{y}_n = V_{n-1}^L - V_n^L + F_{impact} \tag{G.14}$$

Now define a matrix, Y, where:

$$y_i = Y(4i+1) \tag{G.15}$$

$$\dot{y}_i = Y(4i+2) \tag{G.16}$$

$$\theta_i = Y(4i+3) \tag{G.17}$$

$$\dot{\theta}_i = Y(4i+4) \tag{G.18}$$

Solving for the time derivative of Y and considering G.8-G.14:

$$\dot{Y}(1) = \dot{Y}(2) = \dot{Y}(3) = \dot{Y}(4) = 0 \tag{G.19}$$

$$\dot{Y}(4i+1) = \dot{y}_i = Y(4i+2) \quad For\, i > 0 \tag{G.20}$$

$$\dot{Y}(4i+2) = \ddot{y}_i = \left(V_i^R - V_i^L\right)/m_i \quad For\, i \neq n \tag{G.21}$$

$$\dot{Y}(4i+3) = \dot{\theta}_i = Y(4i+4) \tag{G.22}$$

$$\dot{Y}(4i+4) = \ddot{\theta}_i = \left(M_i^R - M_i^L\right)/J_i \tag{G.23}$$

APPENDIX H

COEFFICIENT OF RESTITUTION

The coefficient of restitution (ε) is defined as the relative velocity between two bodies before impact divided by the relative velocity between the two bodies after impact. Looking particularly at the case where a ball is dropped to a plate (Figure H.1):

$$\varepsilon = \frac{v_2}{v_1} \tag{H.1}$$

where: v_2 = velocity of ball just after impact

v_1 = velocity of ball just before impact

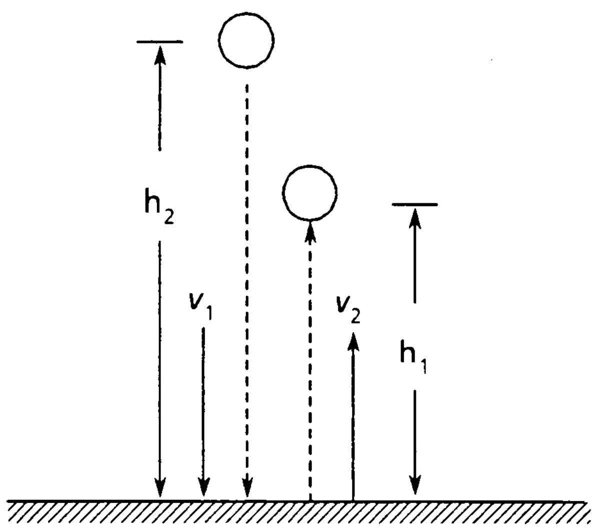


Figure H.1 Action of ball striking plate.

If the ball is dropped from height, h_1:

$$\frac{1}{2} m_{ball} v_1^2 = m_{ball} g h_1 \tag{H.2}$$

$$v_1 = \sqrt{2gh_1} \tag{H.3}$$

Also, if at height h_2, $v = 0$ then:

$$\frac{1}{2} m_{ball} v_2^2 = m_{ball} g h_2 \tag{H.4}$$

$$v_2 = \sqrt{2gh_2} \tag{H.5}$$

Therefore:

$$\varepsilon = \frac{v_2}{v_1} = \frac{\sqrt{2gh_2}}{\sqrt{2gh_1}} = \sqrt{\frac{h_2}{h_1}} \tag{H.6}$$

To determine the coefficient of restitution of a variety of materials, a steel ball was dropped from a height of 10 inches and the maximum height reached after impact was recorded (averaged over 10 trials). Results are recorded in Table H.1.

These values for ε are for a steel ball striking a base of given material. Two discrepancies may occur in this analysis. The detector may be made of a material other than steel and the detector will be striking a check on a base material. With this in mind the coefficient of restitution was found for an

Table H.1. Coefficients of restitution for a variety of metals.

Base Material	h_1 (in)	h_2 (in)	$\varepsilon = \sqrt{h_2/h_1}$
Aluminum	10	4.2 ± .3	.65
Cast Iron	10	4.2 ± .3	.65
Brass	10	4.0 ± .3	.63
Steel	10	3.5 ± .3	.59
Copper	10	2.9 ± .3	.54

aluminum detector striking an aluminum base plate with a document resting on it.

$$h_1 = 5 \text{ units on oscilloscope}$$

$$h_2 = 0.8 \text{ units on oscilloscope}$$

Therefore,

$$\varepsilon = 0.4 \tag{H.7}$$

Upon impact by a document, the detector device will rise to some maximum height, return to the document surface and rebound to some new maximum height with this new height decreasing with a smaller coefficient of restitution. With this in mind, one possible way of decreasing the settling time would be to decrease the coefficient of restitution of the lever arm/base system. Plastics would be expected to exhibit a coefficient of restitution lower than those of the metals given in Table H.1. Therefore, settling time could be decreased using materials for the base plate and/or lever arm with lower coefficients of restitution than aluminum (i.e. other metals, composite materials, plastics, etc.).

The value of $\varepsilon = 0.4$ will be used in the initial theoretical analysis of the system. However once experiments are performed, the value of the coefficient of restitution will be changed so that the theoretical response most nearly conforms to the actual experimental response. It is very likely that this value would change, because of the fact that the motion of the document under the arm has been disregarded.

APPENDIX I

CALCULATION OF NATURAL FREQUENCY AND LOGARITHMIC DECREMENT

Two variables of interest associated with damped oscillatory motion are the natural frequency and the logarithmic decrement. The natural frequency (ω) is simply the reciprocal of the period of oscillatory motion. For a damped system, the damped natural frequency (ω_d) is described as follows

$$\omega_d = \frac{2\pi}{\tau_d} \tag{I.1}$$

where τ_d is the damped frequency.

The logarithmic decrement (δ) is used to measure the rate of decay of free oscillations and is defined as follows.

$$\delta = \frac{1}{n} \ell n \frac{x_o}{x_n} \tag{I.2}$$

where

n = number of cycles

x_0 = amplitude of first cycle

x_n = amplitude of last cycle

Figure I.1 shows a sample oscilloscope trace used for calculating these quantities. Individual beams used in experimentation were isolated and excited manually. The oscilloscope trace shown is that of the optimal beam design.

$n = 28$ cycles

number of horizontal divisions $= 9.6$ div

1 horizontal division $= 20$ msec

$x_o = 7.0$ div

$x_n = 2.1$ div

$$\omega_d = \left(\frac{28\ cycles}{9.6\ div}\right)\left(2\pi\ \frac{rad}{cycle}\right)\left(\frac{div}{2\,msec}\right)\left(\frac{1000\ msec}{sec}\right)$$

$$\cdot\ \omega_d = 916.3\ \frac{rad}{sec}$$

$$\delta = \frac{1}{28}\ \ell n\left(\frac{7.0\ div}{2.1\ div}\right)$$

$$\delta = .0430$$

Table I.1 is a compilation of these values for all the flexible cantilever beams used in testing.

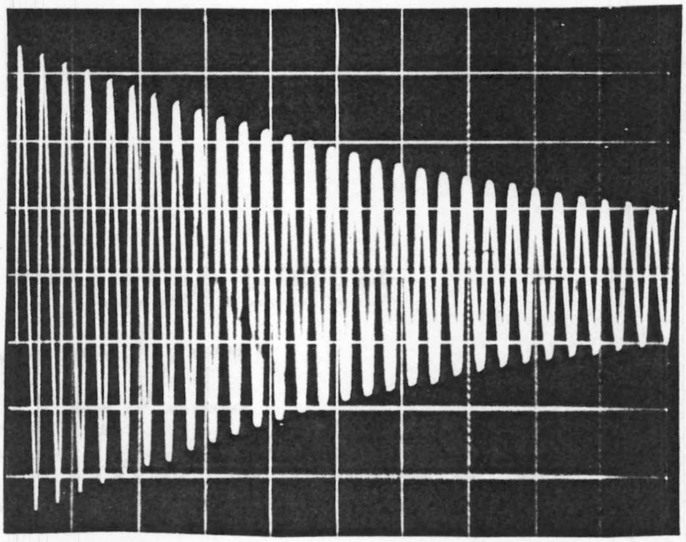


Figure I.1. Oscilloscope trace used for calculating beam properties.

Table I.1 Characteristics of flexible beams.

beam thickness (in)	total beam length (in)	damped natural frequency (rad/sec)	logarithmic decrement
.008	1.25	754.0	.0149
.010	1.25	816.8	.0131
.008	1.50	534.7	.0665
.010	1.50	802.1	.0429
.011	1.50	916.3	.0430
.012	1.50	961.7	.0423
.010	1.75	577.0	.0195
.012	1.75	751.3	.0260

APPENDIX J

VIBRATION ANALYSIS

1. INTRODUCTION

The following graphs are plots of the frequency spectrum generated by the Hewlett Packard 5420 B Digital Signal Analyzer at various sites in the lower transport region of the IBM 1255 reader-sorter (as described in Figure J.1). These are included to illuminate the effect of vibrations at various sites. Discussion is included under each figure.

Each graph is the plot of an average value of the magnitude of the acceleration (a real time average taken over at least 50 trials over a period of approximately one minute) vs. the frequency of vibration. Also given on the following figures are the magnitudes of the displacement corresponding to integer multiples of the fundamental frequency of the motor (1725 rpm) and harmonics of the line frequency (60 Hz). The maximum displacement is also included if it does not correspond to one of these harmonics.

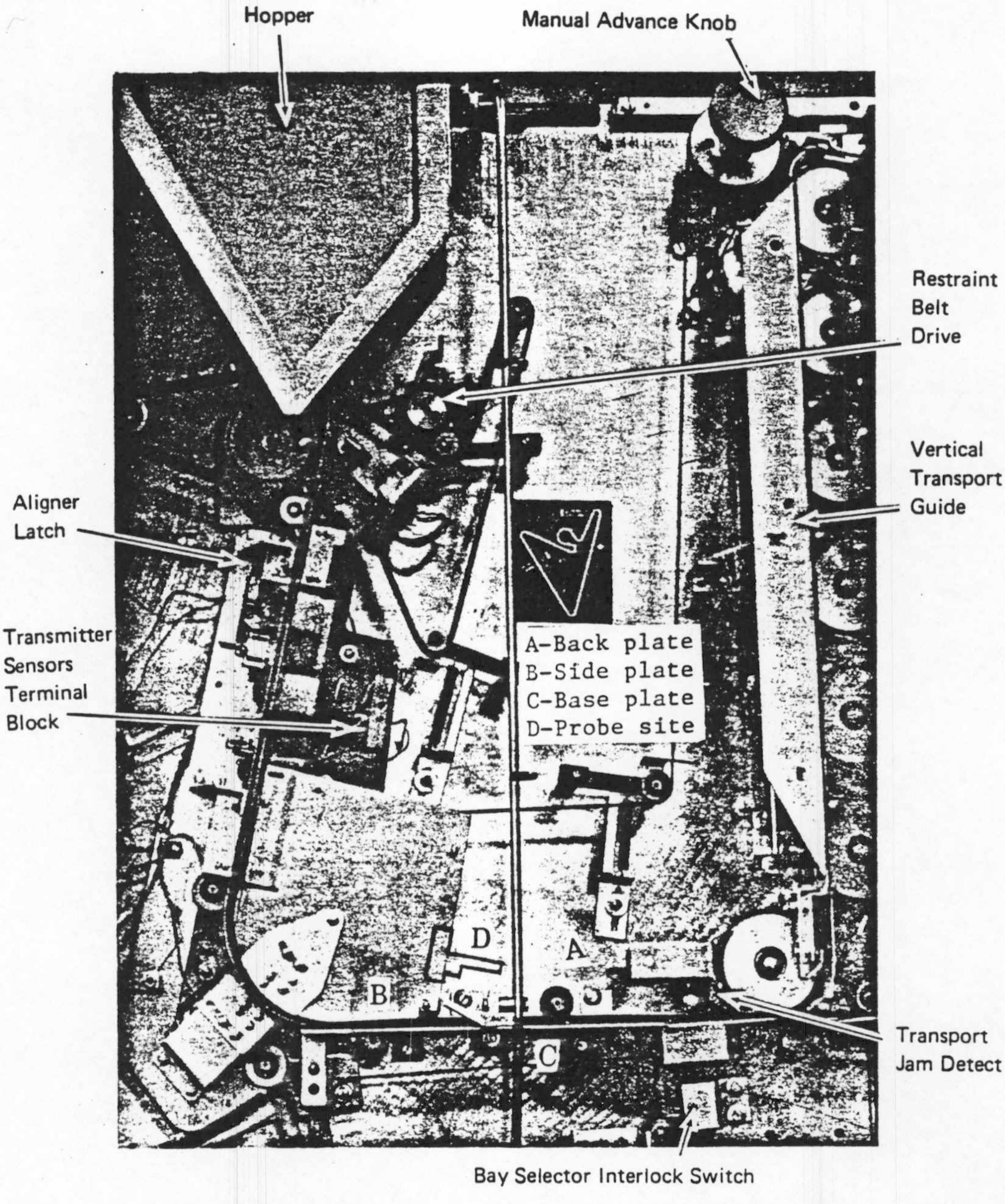
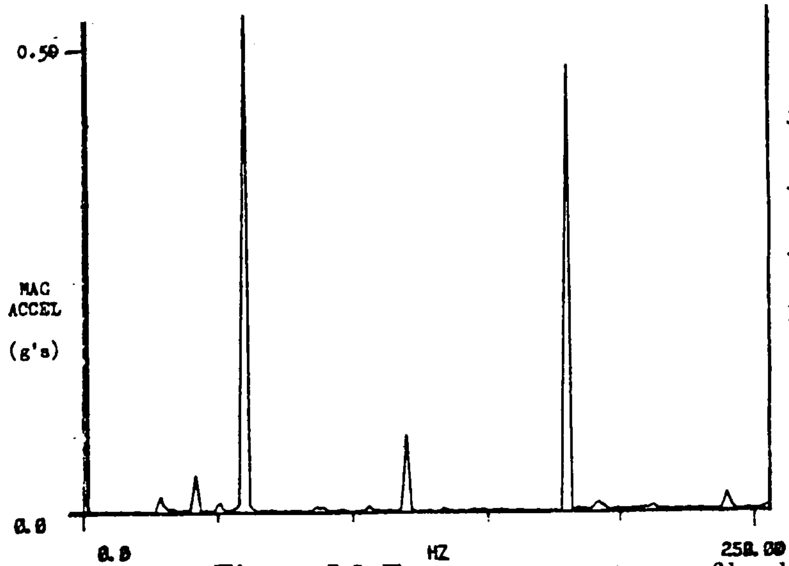


Figure J.1. Location of accelerometer readings.

Source: IBM manual for the 1255 check reader-sorter, 18 August 1978, p. 9-1.

2. PLOTS OF FREQUENCY SPECTRUM



x_{60} = 1494 µin

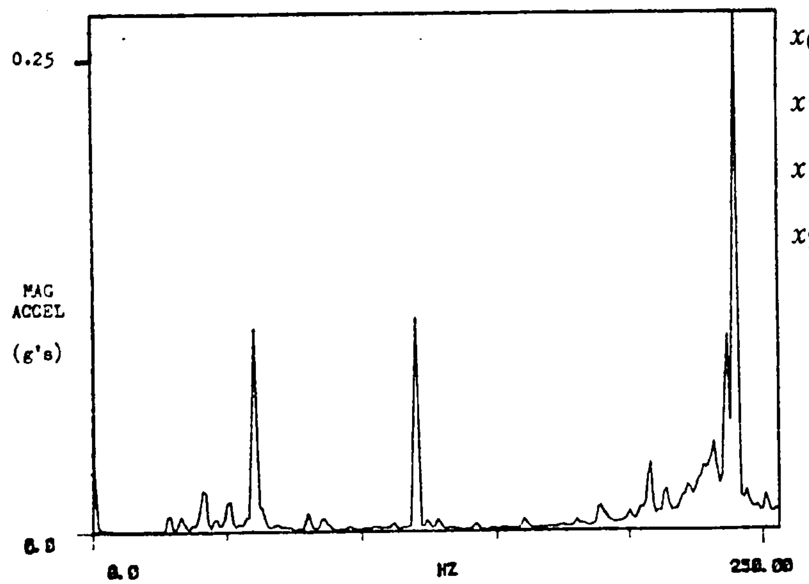
x_{120} = 57µin

x_{180} = 141 µin

x_{240} = 3 µin

Figure J.2 Frequency spectrum of back plate.

Note: The frequency spectrum of the back plate does not depend on whether or not checks are passing through the transport region.



x_{60} = 272 µin

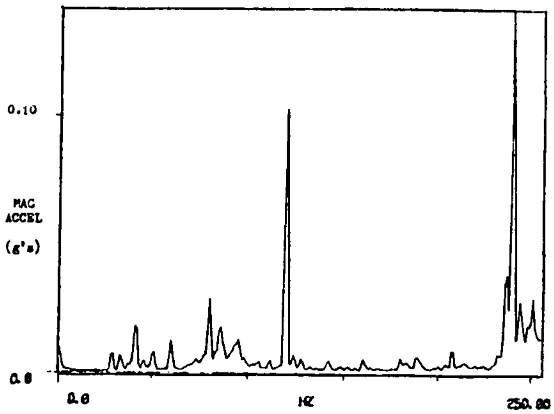
x_{130} = 74 µin

x_{180} = 3 µin

x_{240} = 46 µin

Figure J.3. Frequency spectrum of side plate (1).

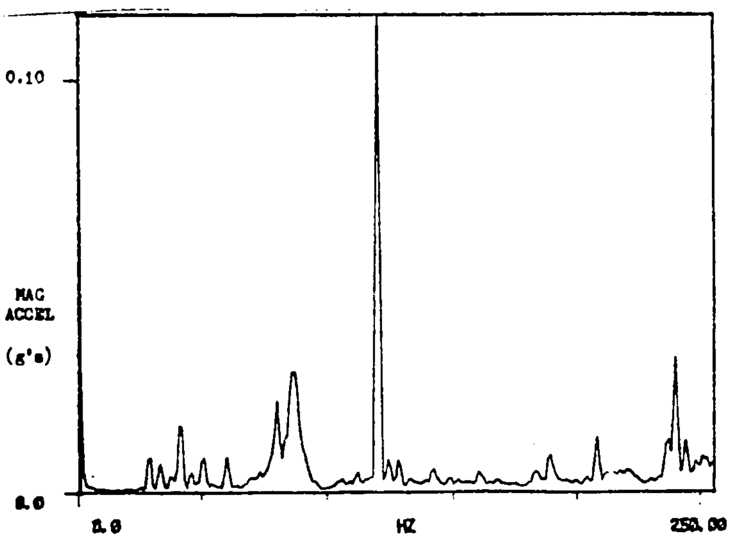
Note: This is with no deflector arm attached on the side plate. The frequency spectrum does not depend on whether or not checks are running through.



$$x_{40} = 114 \ \mu in$$
$$x_{60} = 45 \ \mu in$$
$$x_{120} = 74 \ \mu in$$
$$x_{180} = 3 \ \mu in$$
$$x_{240} = 24 \ \mu in$$

Figure J.4. Frequency spectrum of side plate (2).

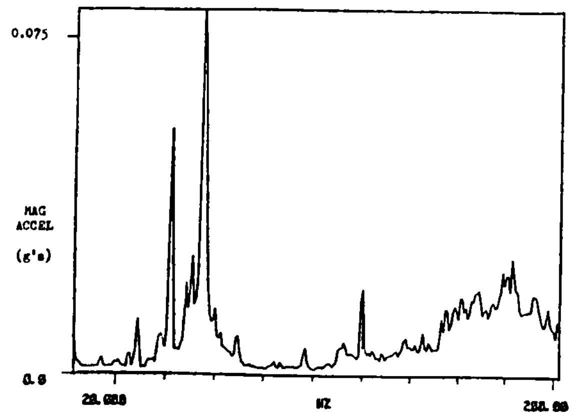
Note: Rubber damping was added to the supports of the side plate to reduce the vibration. This was sufficient to reduce the peak at f = 60 Hz by a factor of six. Also, the peak at f = 240 Hz was reduced by a factor of two. Adding the structural damping shifted the maximum displacement to f = 40 Hz.



$$x_{40} = 204 \mu in$$
$$x_{60} = 23 \ \mu in$$
$$x_{120} = 79 \ \mu in$$
$$x_{180} = 3 \ \mu in$$
$$x_{240} = 6 \ \mu in$$

Figure J.5. Frequency spectrum of side plate (3).

Note: The rubber damping was removed and a heavy deflector arm (m = approx. 0.1 kg) was clamped to the side plate. The increase of the moment of inertia of the plate caused a substantial decrease in the high frequency peak, while the peak at f = 120 Hz remained virtually the same. The peak at f=60 Hz decreased by a factor of 10. However, increasing the moment of inertia increased the maximum low frequency peak at f = 40 Hz by a factor of two.



x_{40} = 356μin

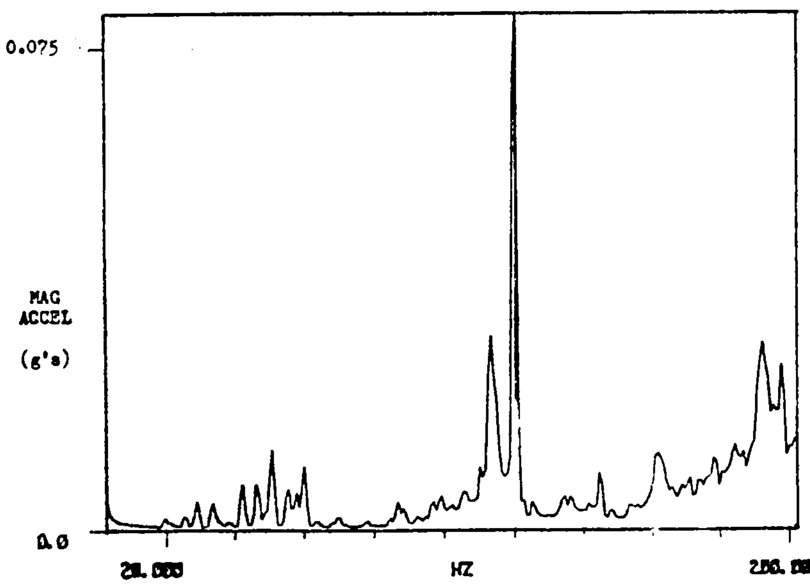
x_{60} = 226μin

x_{120} = 13μin

x_{180} = 8 μin

Figure J.6. Frequency spectrum of base plate (1).

Note: Frequency spectrum was obtained with checks passing over the base plate. Greater magnitudes of displacement were obtained for low frequencies.



x_{25} = 65 μin

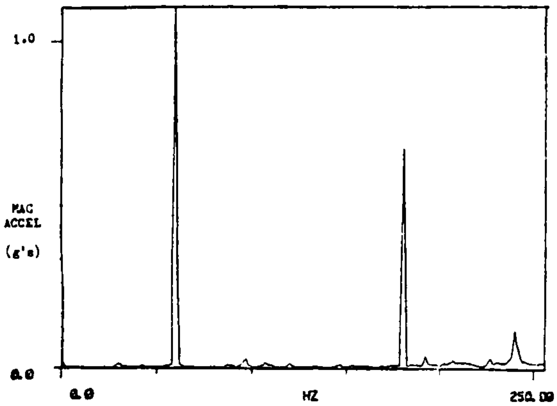
x_{60} = 23 μin

x_{120} = 55 μin

x_{180} = 4 μin

Figure J.7. Frequency spectrum of base plate (2).

Note: A section of stiff rubber tubing was clamped against the base plate to damp vibrations. Note that the lower frequency peaks are decreased substantially. This peak shifts to f = 110 Hz. Checks were passing over the base plate on this trial, also.



$x_{60} = 2943\ \mu in$

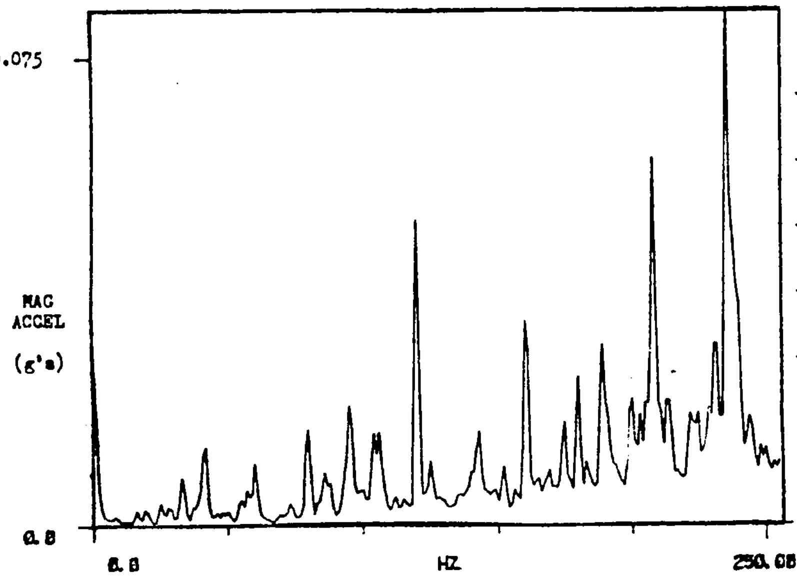
$x_{120} = 8\ \mu in$

$x_{180} = 201\ \mu in$

$x_{240} = 14\ \mu in$

Figure J.8. Frequency spectrum of base plate (3).

Note: The conditions for this trial are identical to those of the previous trial, but much more pronounced peaks occur in this frequency spectrum. This could be due to the fact that the accelerometer was placed very near a supporting structure in the machine.



$x_{40} = 71\ \mu in$

$x_{60} = 32\ \mu in$

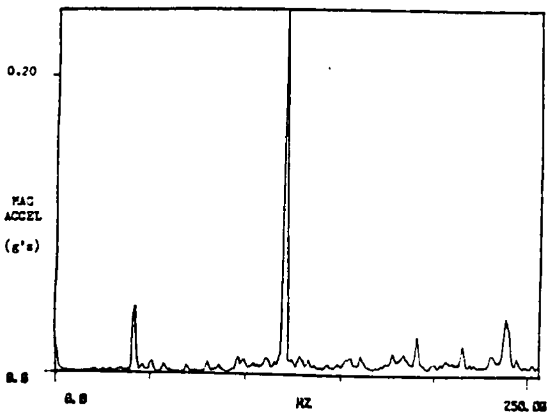
$x_{120} = 34\ \mu in$

$x_{180} = 13\ \mu in$

$x_{240} = 14\ \mu in$

Figure J.9. Frequency spectrum of base plate (4).

Note: This spectrum was obtained without checks passing over the base plate with the structural damping. The damping has reduced the low frequency peaks.



$x_{40} = 244\ \mu\text{in}$

$x_{60} = 5\ \mu\text{in}$

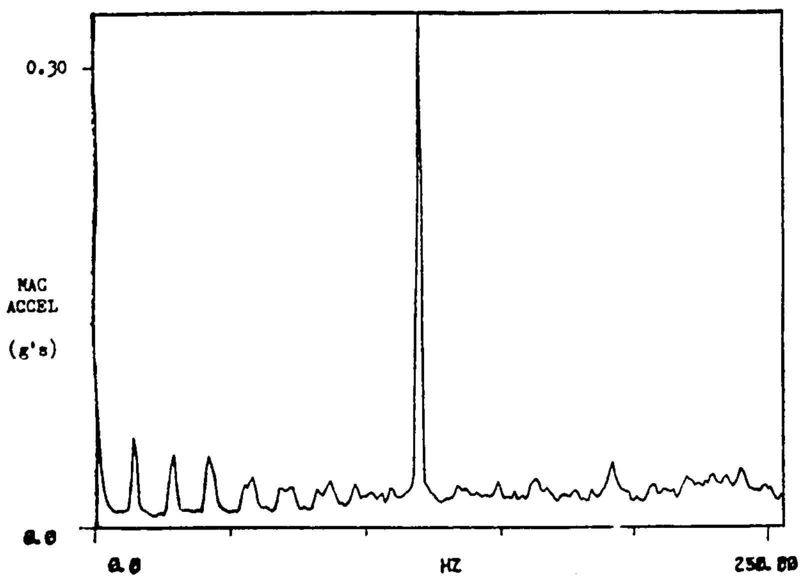
$x_{120} = 164\ \mu\text{in}$

$x_{180} = 9\ \mu\text{in}$

$x_{240} = 6\ \mu\text{in}$

Figure J.10. Frequency spectrum of base plate (5).

Note: This spectrum was obtained with no checks passing through and with the deflector arm attached.



$x_{20} = 1467\ \mu\text{in}$

$x_{60} = 95\ \mu\text{in}$

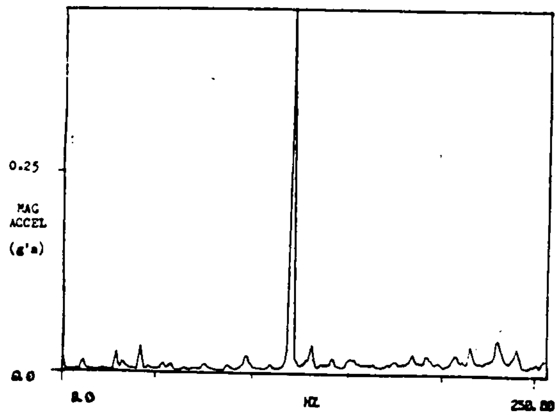
$x_{120} = 238\ \mu\text{in}$

$x_{180} = 8\ \mu\text{in}$

$x_{240} = 6\ \mu\text{in}$

Figure J.11. Frequency spectrum of base plate (6).

Note: This spectrum was obtained with the deflector arm attached and with checks passing through. Notice that the low frequency peaks increased substantially.



$x_{60} = 41$ µin

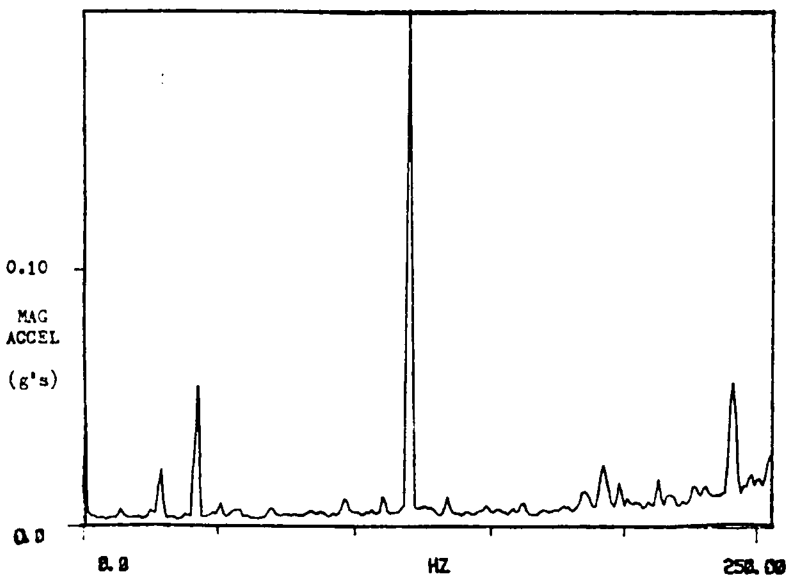
$x_{120} = 311$ µin

$x_{180} = 5$ µin

$x_{240} = 6$ µin

Figure J.12. Frequency spectrum of base plate (7).

Note: This spectrum was obtained with the deflector arm attached and with IBM cards passing through. Notice that the low frequency peaks decrease substantially due to the heavier cards passing through, but the peak at $f = 120$ Hz increases.



$x_{40} = 346$ µin

$x_{60} = 45$ µin

$x_{120} = 214$ µin

$x_{180} = 4$ µin

$x_{240} = 7$ µin

Figure J.13. Frequency spectrum of probe site.

Note: This is the vibration spectrum at the actual site of the probe on the probe holder with checks passing through.

APPENDIX K

EFFECT OF FILTERING

A simple passive low pass filter was included in the system to reduce the noise effects. Figure K.1 shows the description of the filter. The filter included a capacitor of constant capacitance with a variable resistor.

The low pass filter will allow low frequency signals to pass while reducing higher frequency signals (see Figure K.1)

To find an optimum frequency, the resistance was varied and the subsequent effect on the experimental output was recorded. Figure K.2 illustrates this point. The optimum frequency filtered out much of the high frequency noise while maintaining a steep rise and decline at the edges of the document. As the variable resistance was increased, this slope decreases.

The optimum value for the time constant (RC) of the filter was found to be .001 seconds.

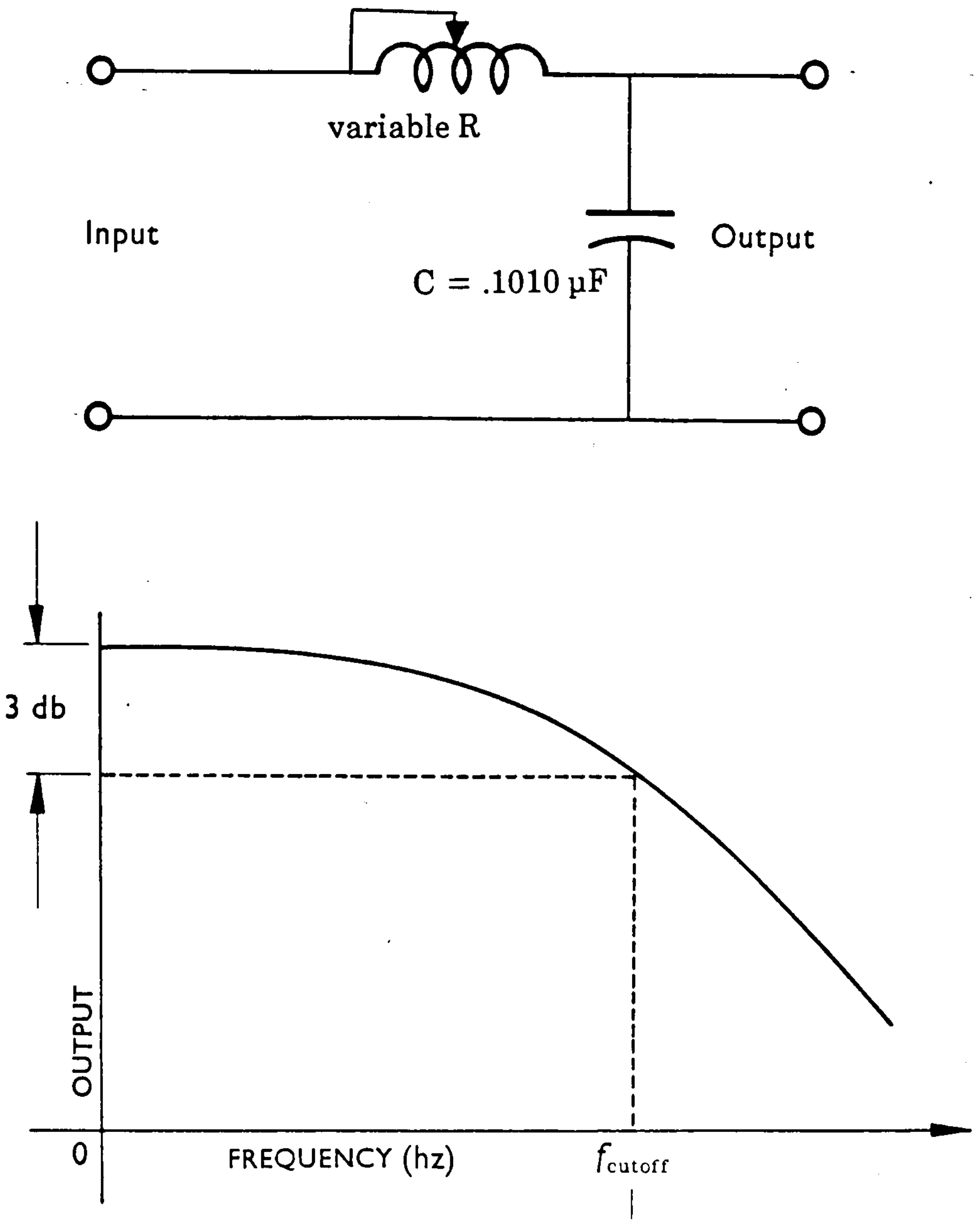


Figure K.1 Filter description.

Source: Carl B. Weick, Principles of Electronic Technology (Toronto: McGraw-Hill Company of Canada Limited, 1969), p. 312.

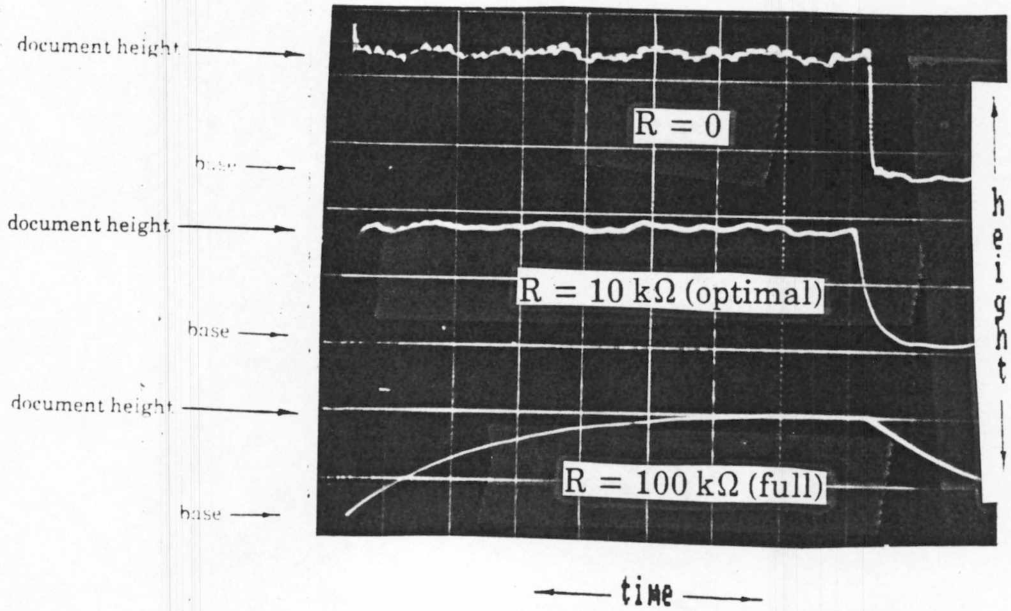


Figure K.2 Effect of varying resistance.

APPENDIX L

COMPARISON OF EXPERIMENTAL AND THEORETICAL BEAM RESPONSES

In order to test the validity of the discrete beam model, the initial response of the beam upon impact was photographed for several different beams. This experimental response is compared to the computer output of the theoretical model response in Figure L.1.

Any theoretical model for the impact response of this system is difficult to define because of the flexibility of the check allowing its edge to turn up and strike the beam at a different angle and location on the beam. Also, any crease or tear in the check would significantly affect the beam response. In light of these considerations, the computer model very nearly predicts the response of most of the beams (particularly the initial slope of the displacement and the maximum height).

Table L.1 summarizes the result of the plots.

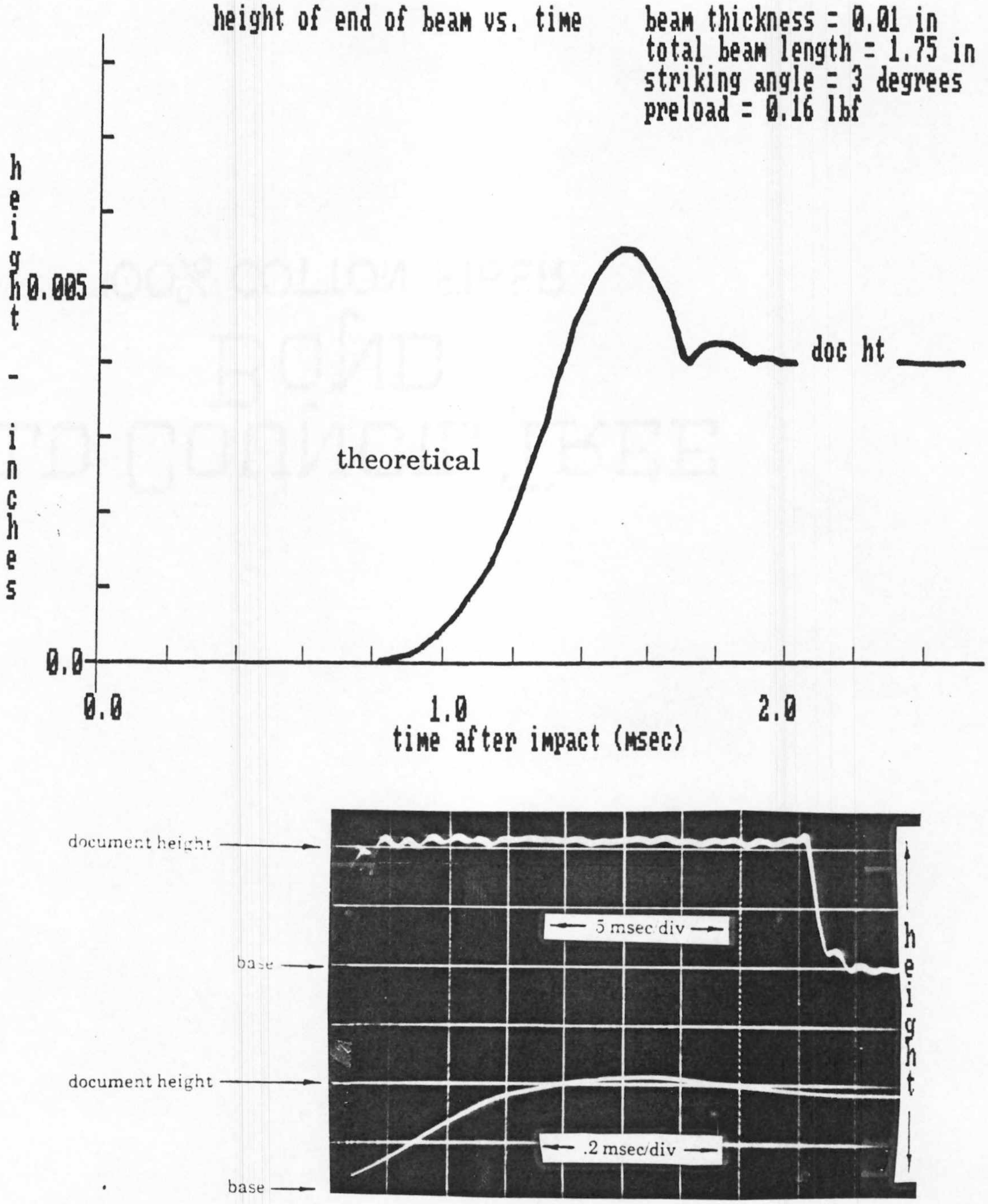


Figure L.1. Comparison of experimental and theoretical beam responses for cantilever beams.

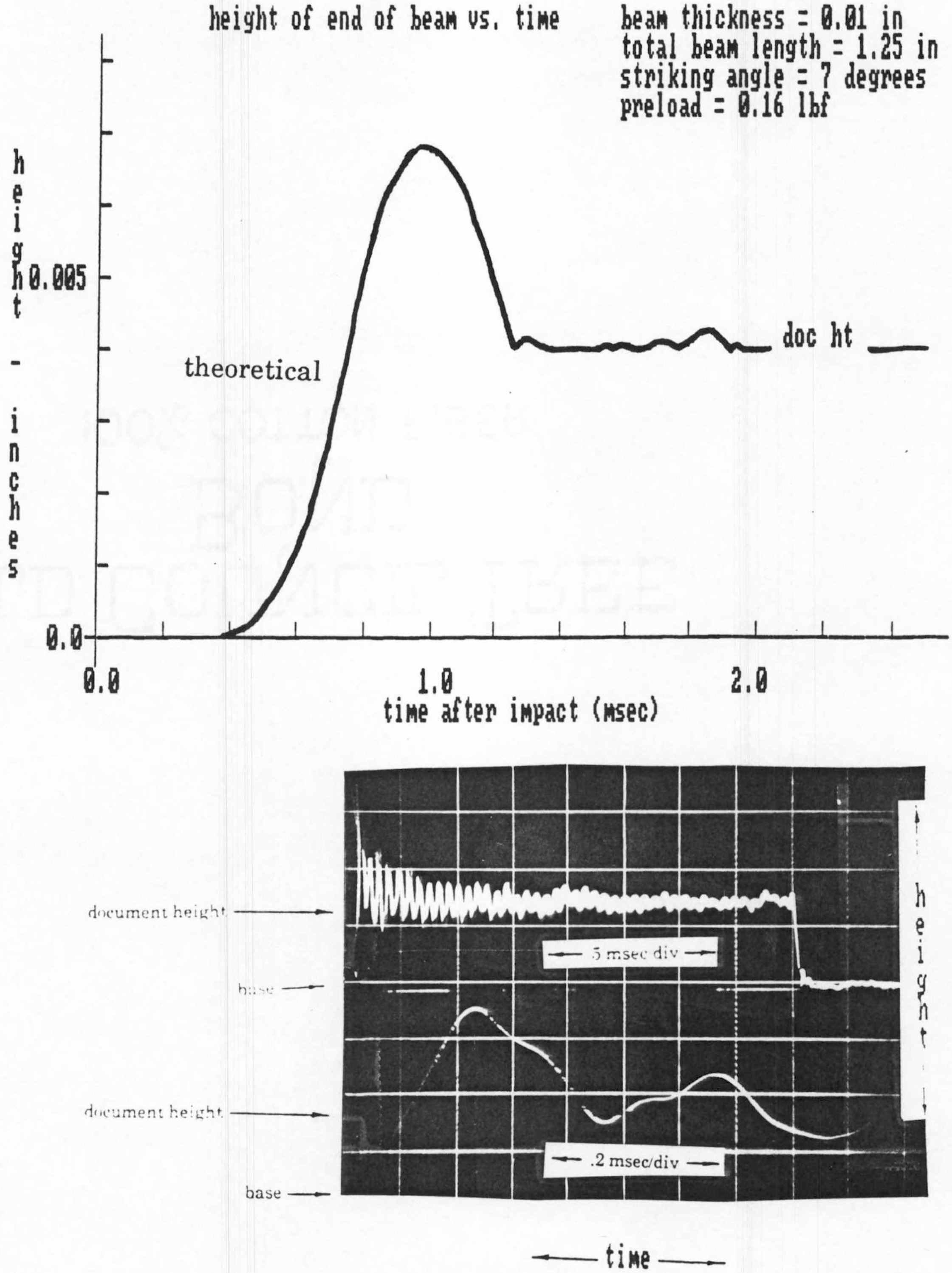


Figure L.1 (continued).

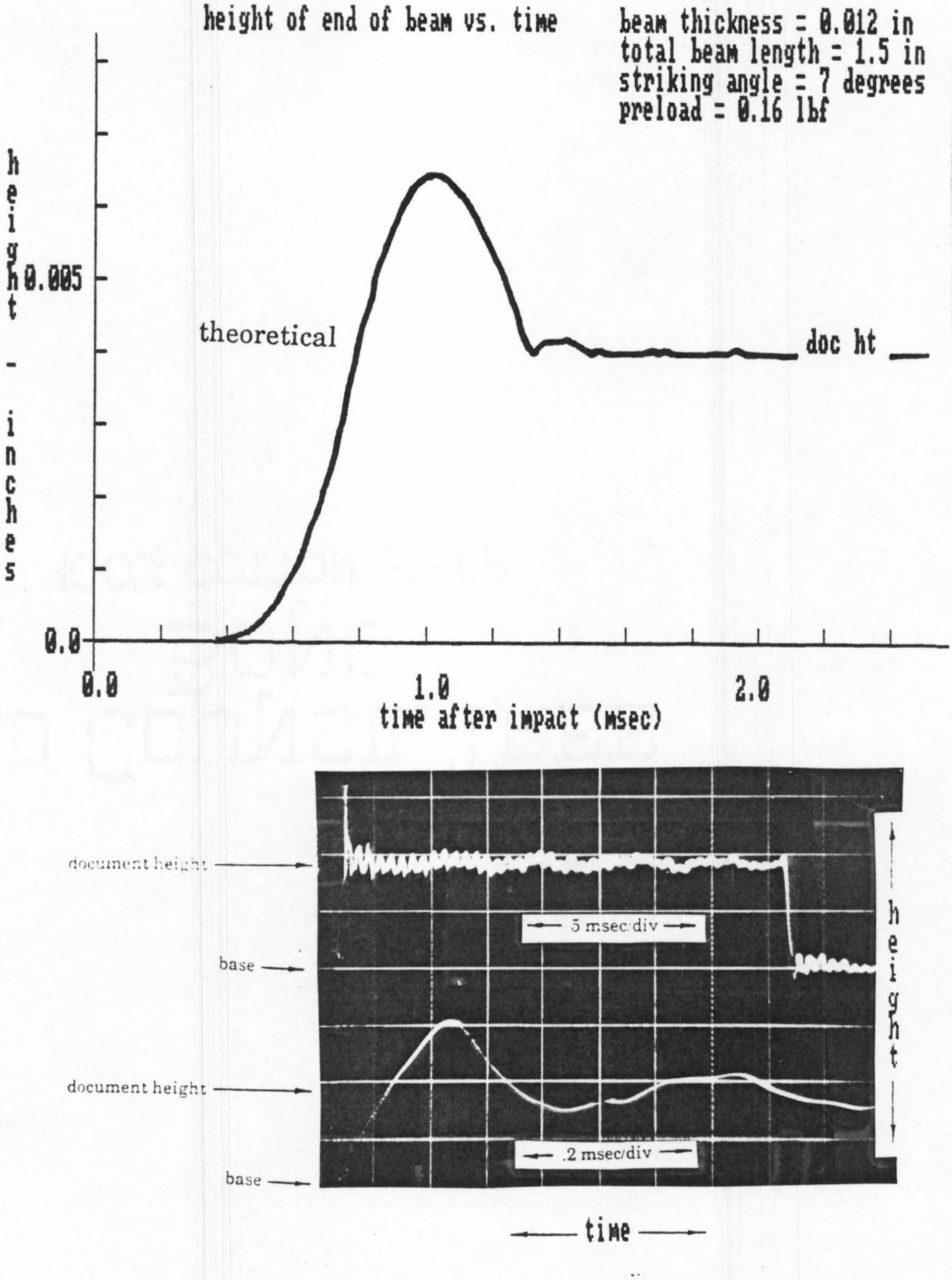


Figure L.1 (continued).

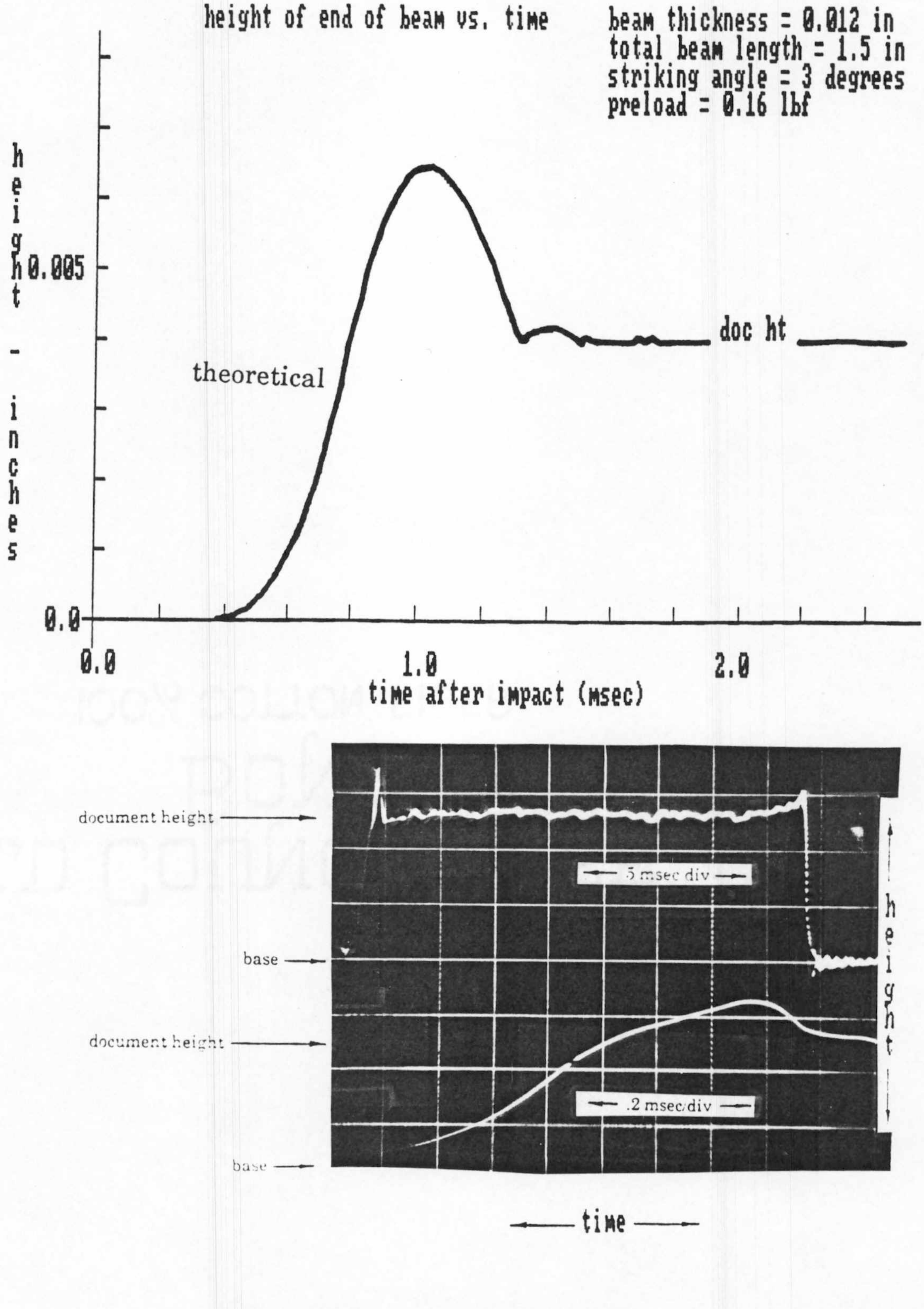
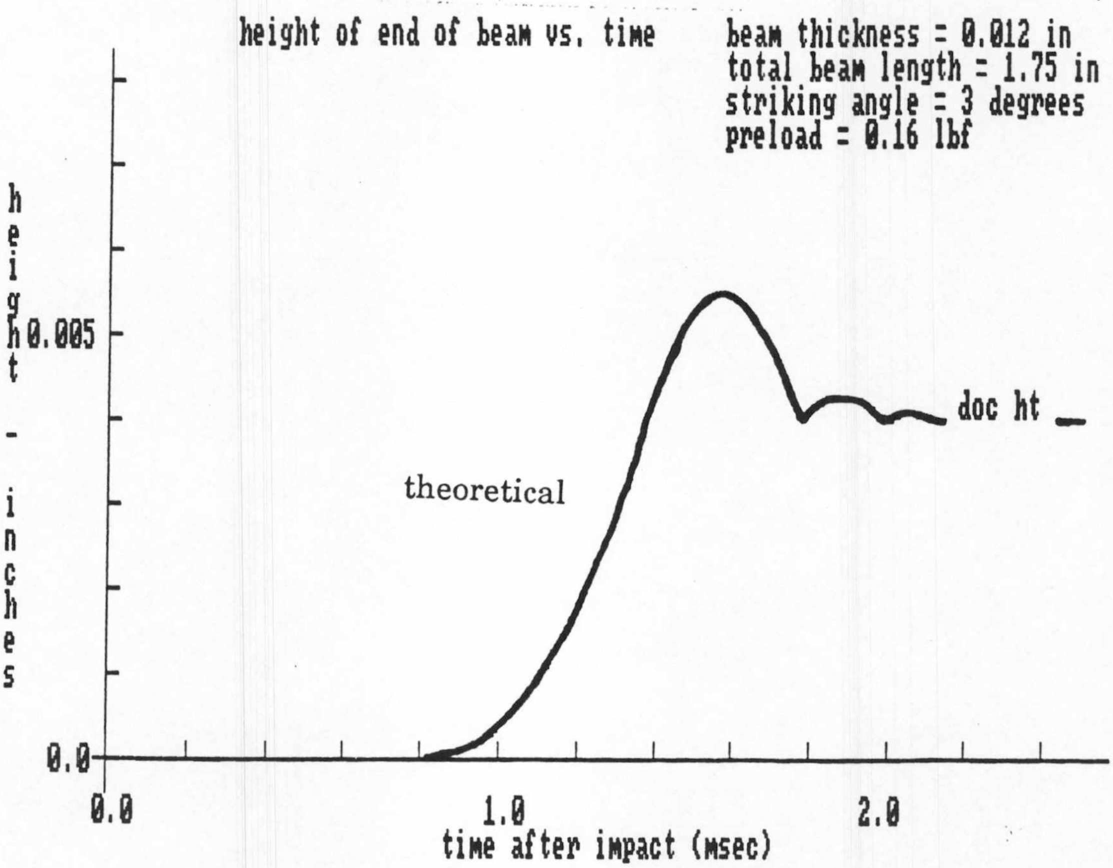


Figure L.1 (continued).



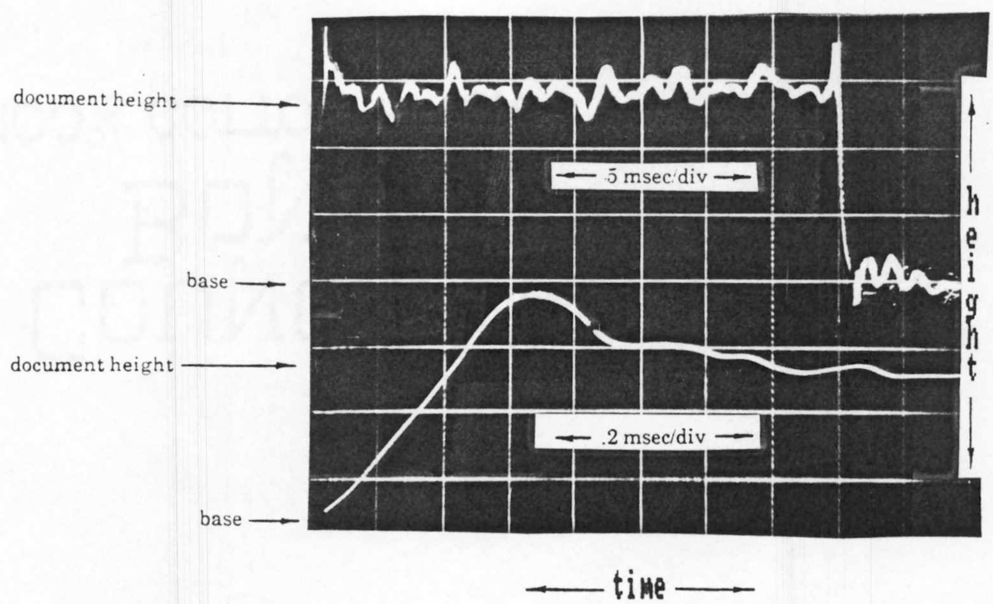


Figure L.1 (continued).

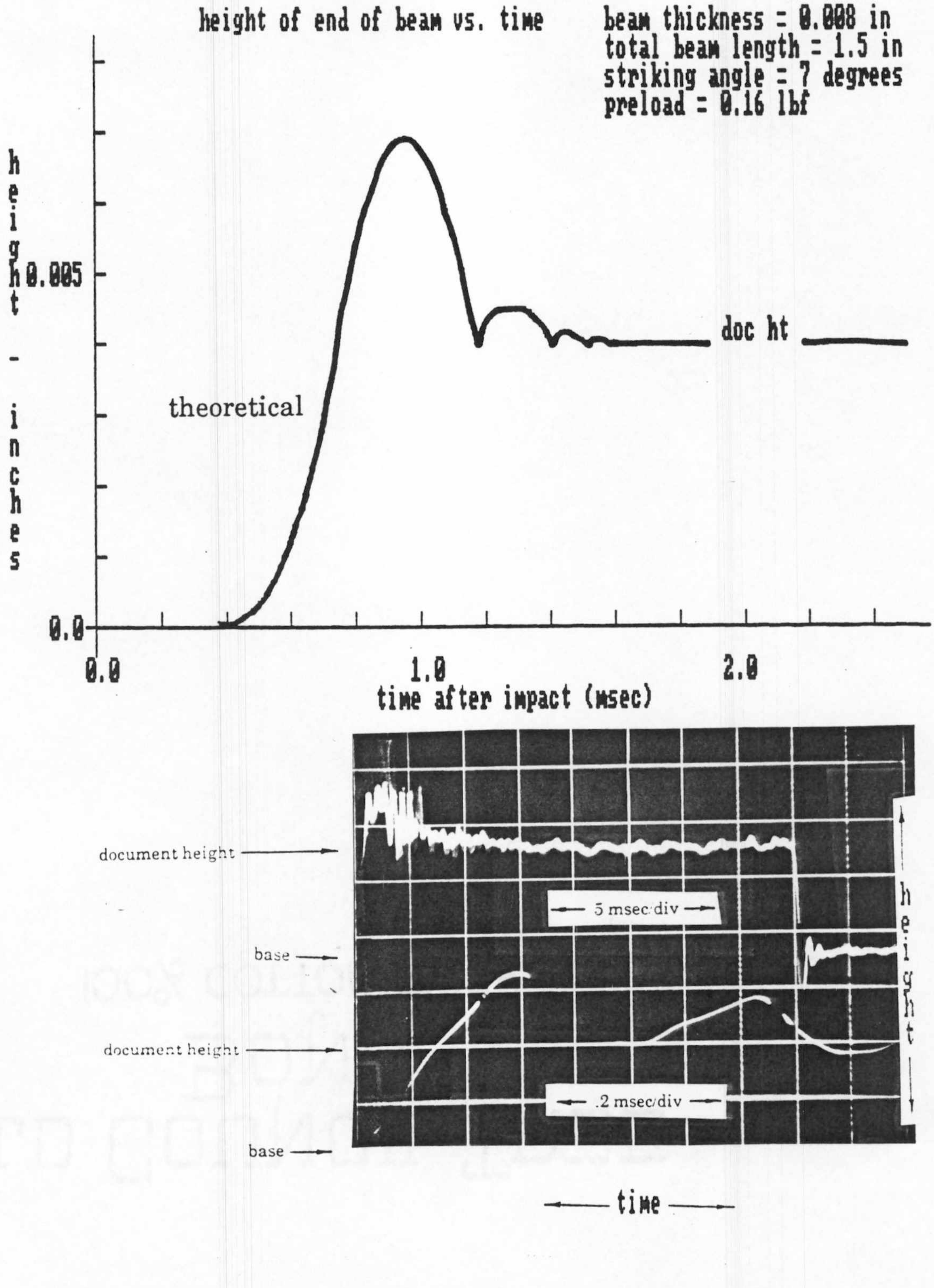
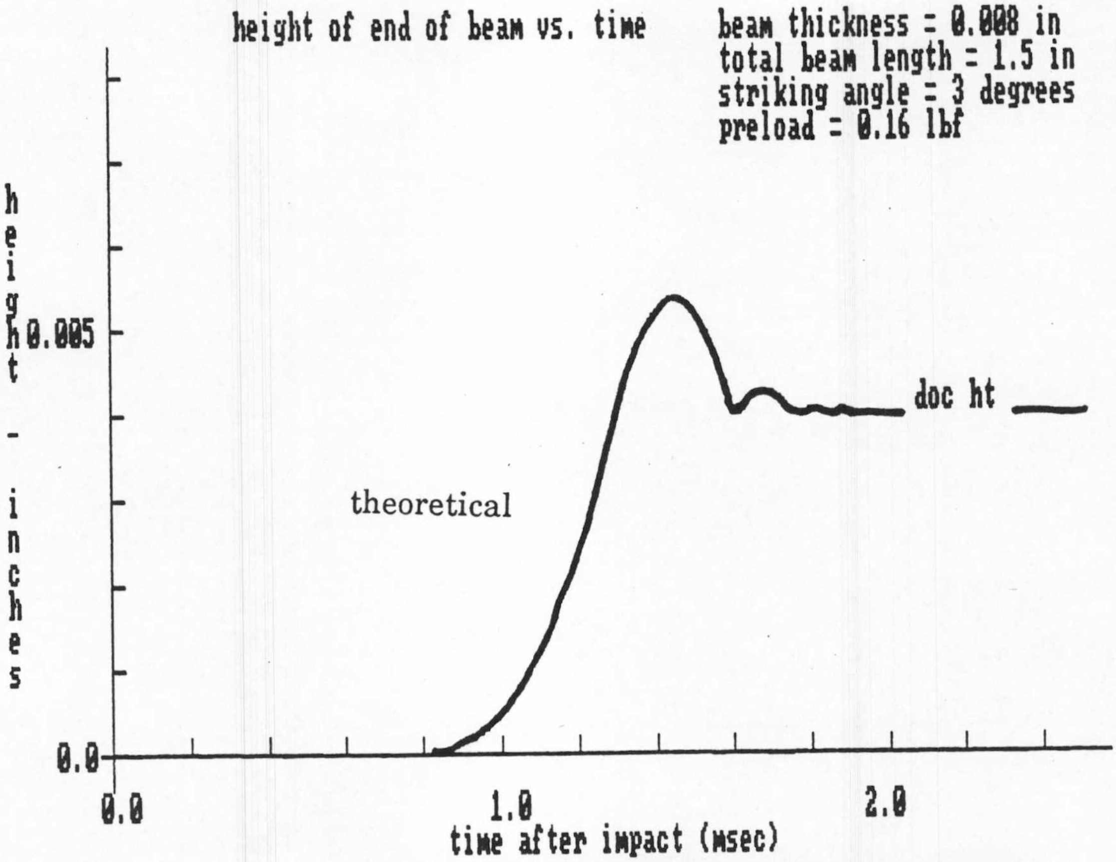


Figure L.1 (continued).



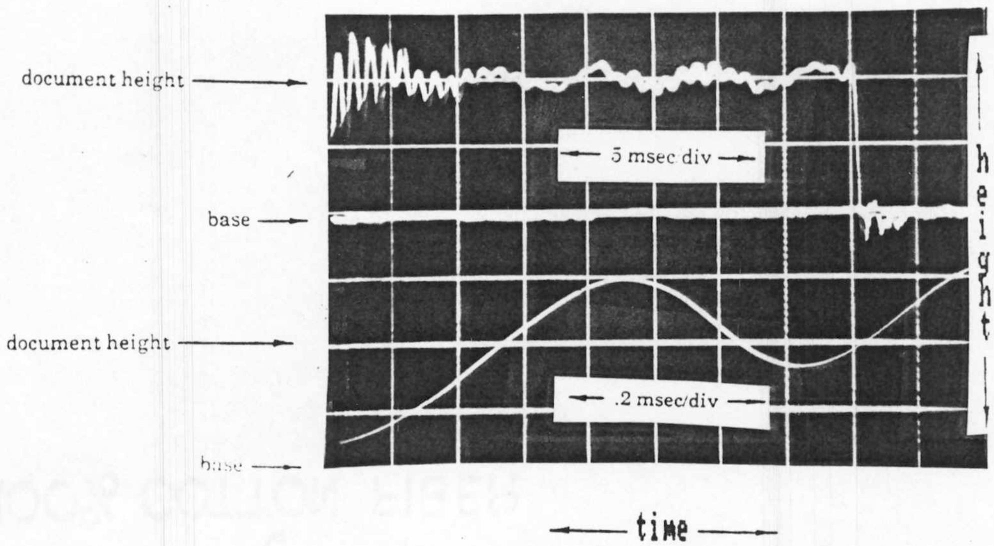
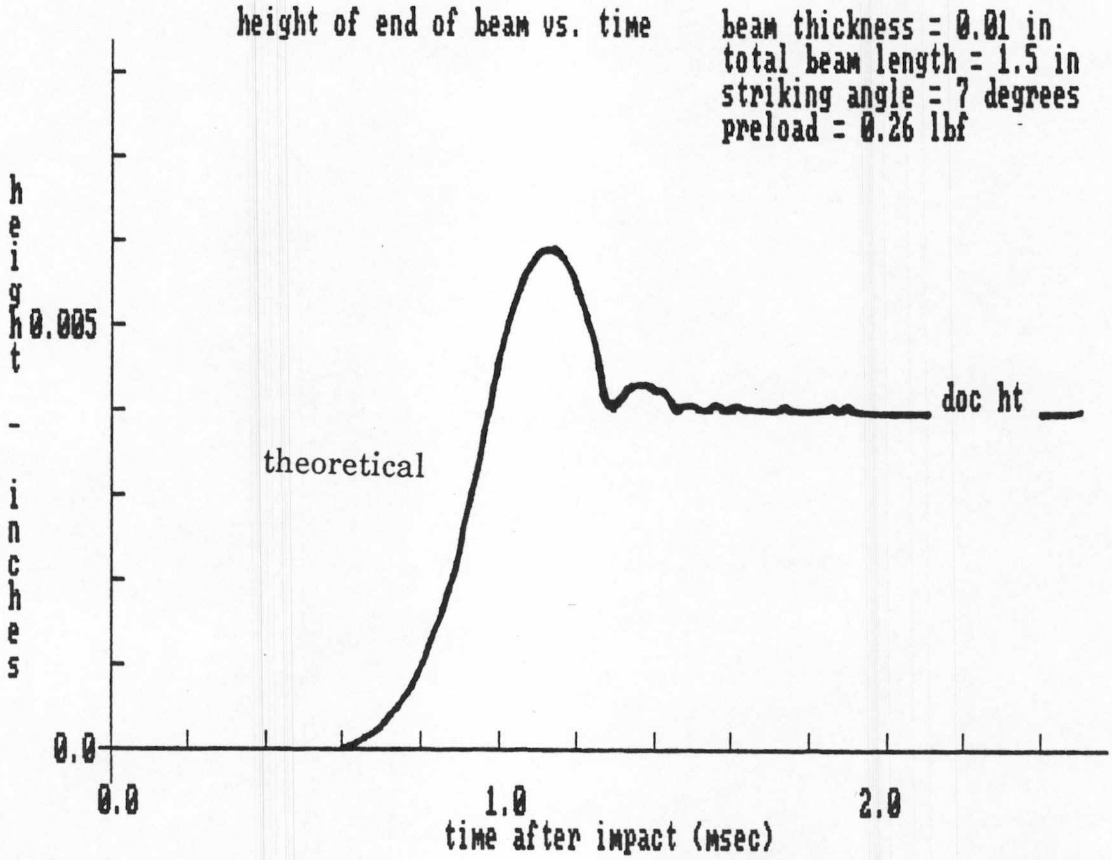


Figure L.1 (continued).



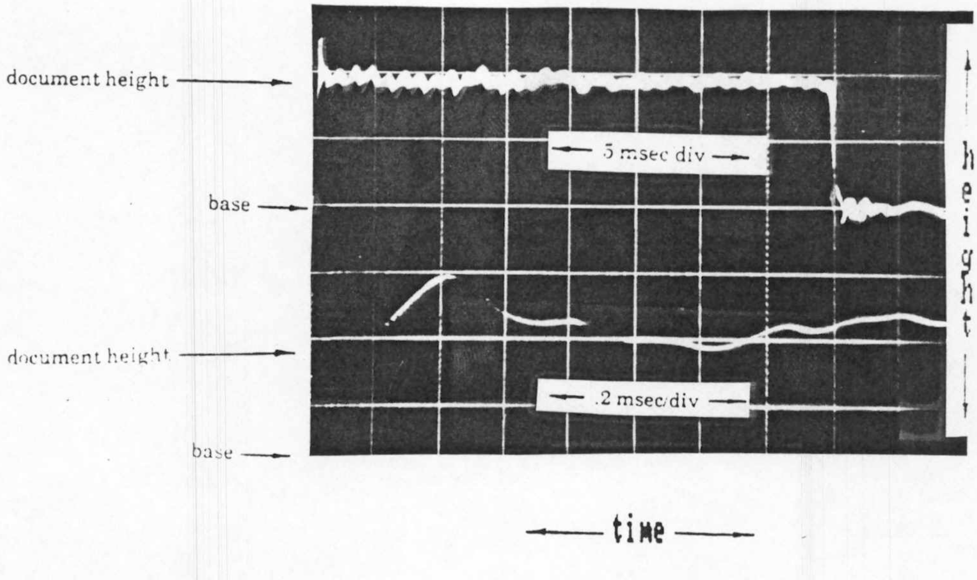


Figure L.1 (continued).

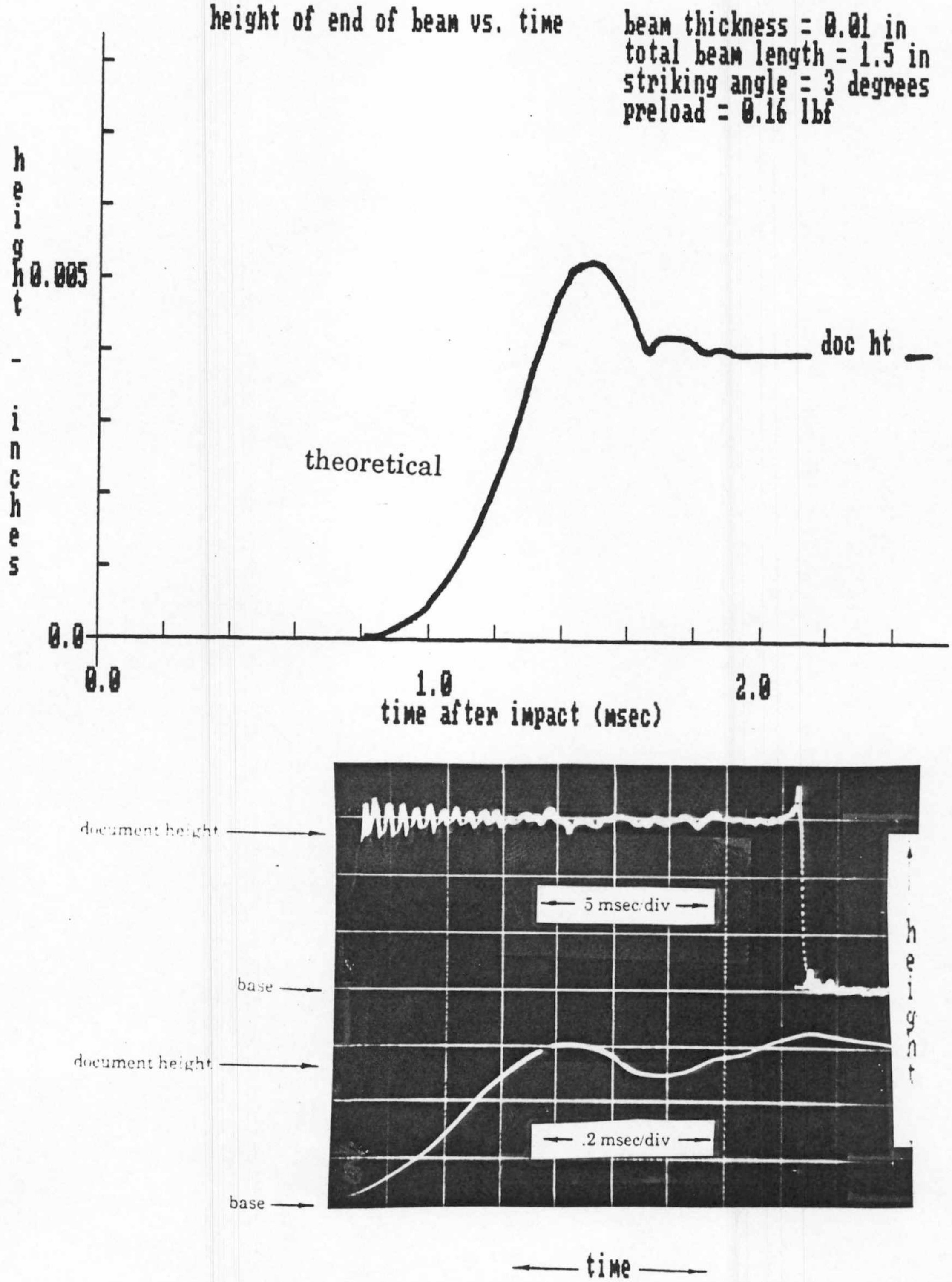
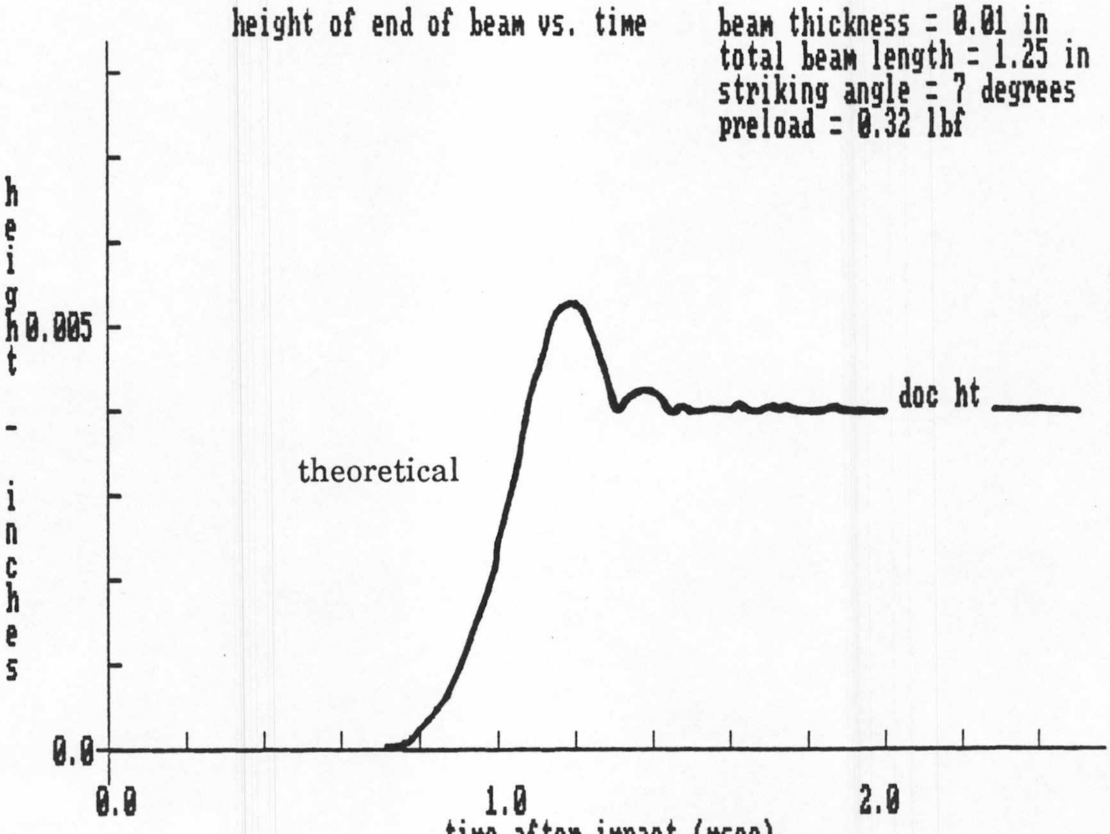


Figure L.1 (continued).



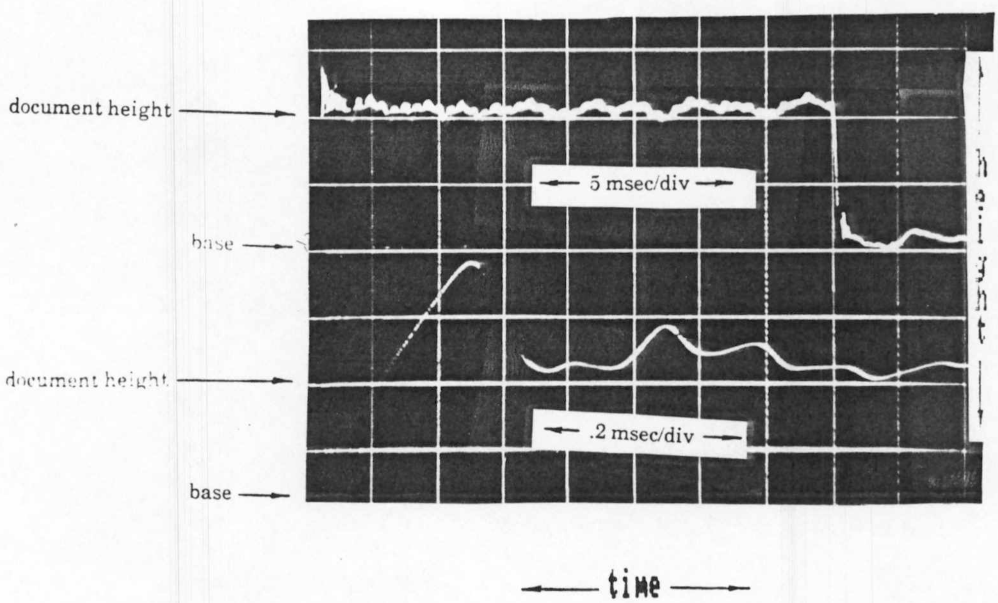


Figure L.1 (continued).

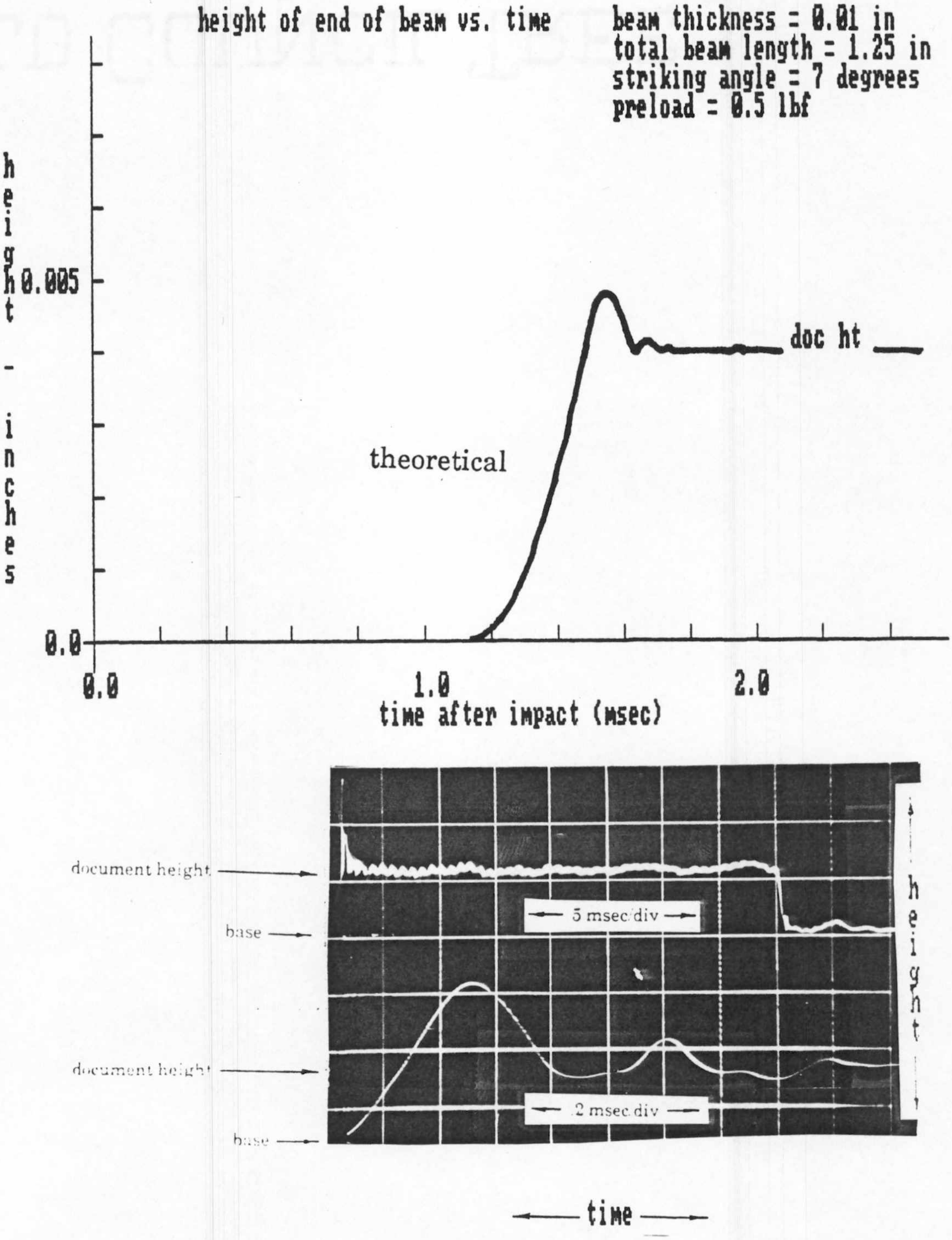
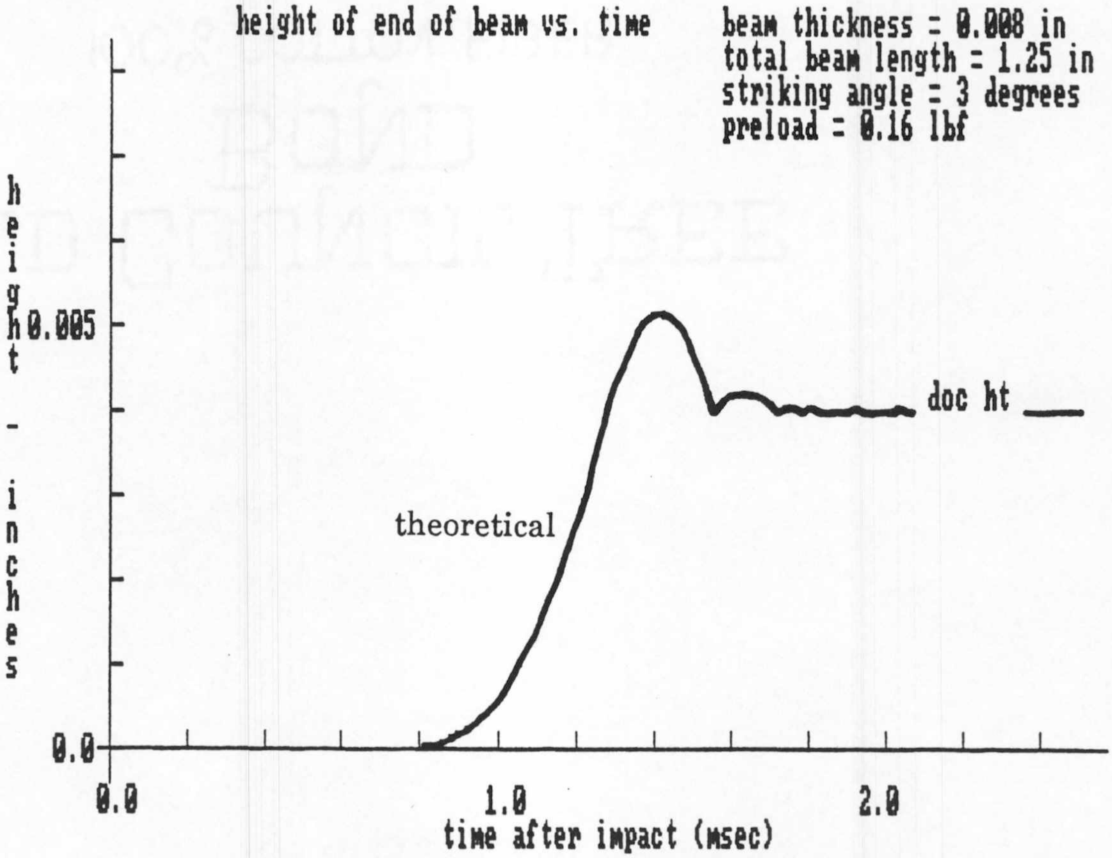


Figure L.1 (continued).



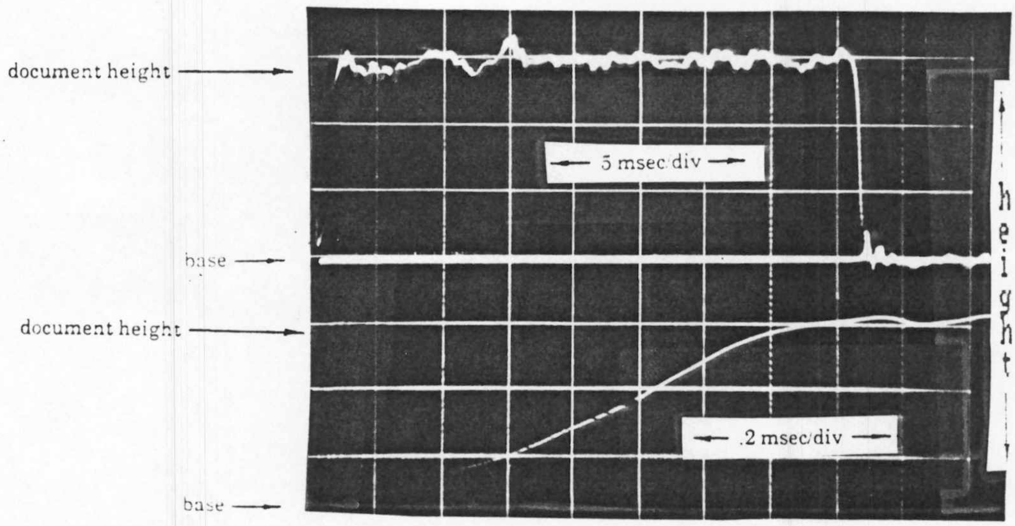
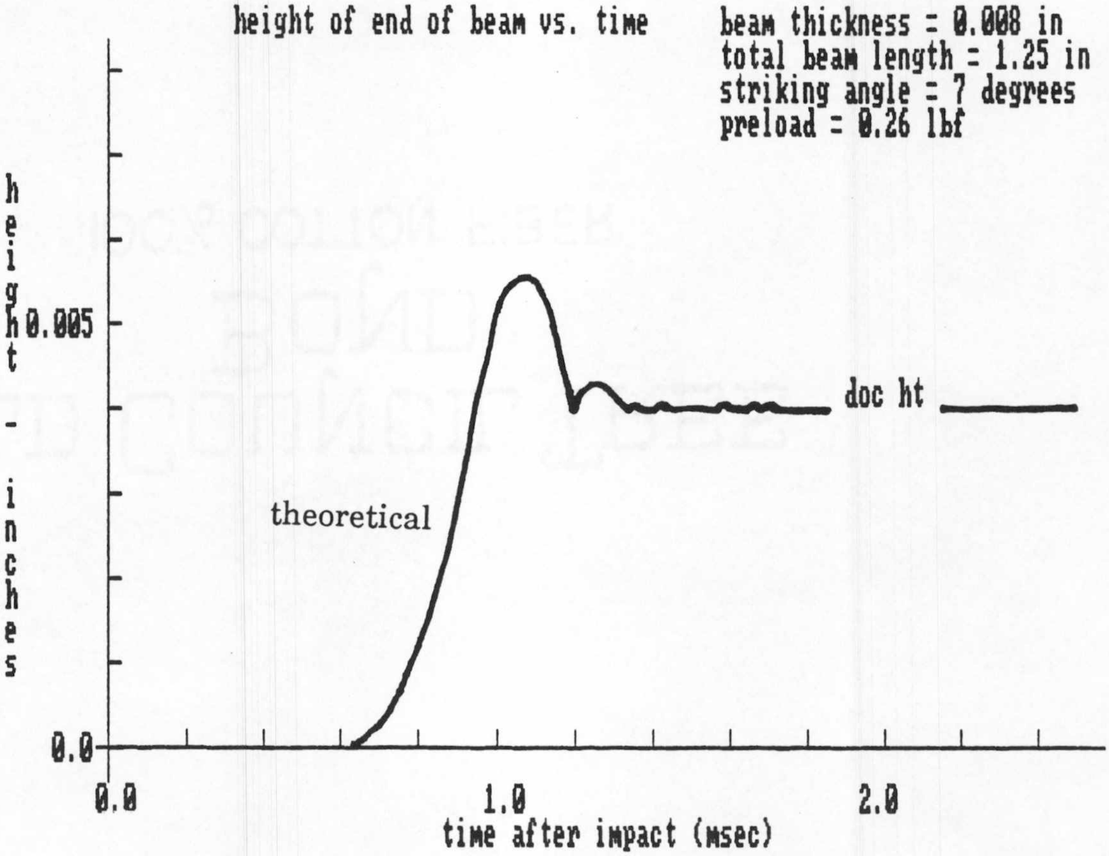


Figure L.1 (continued).



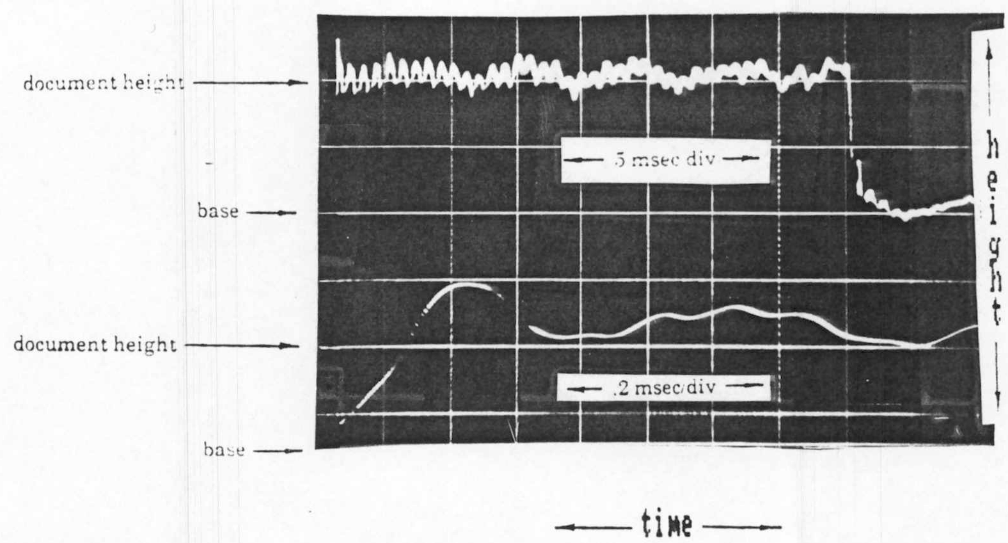


Figure L.1 (continued).

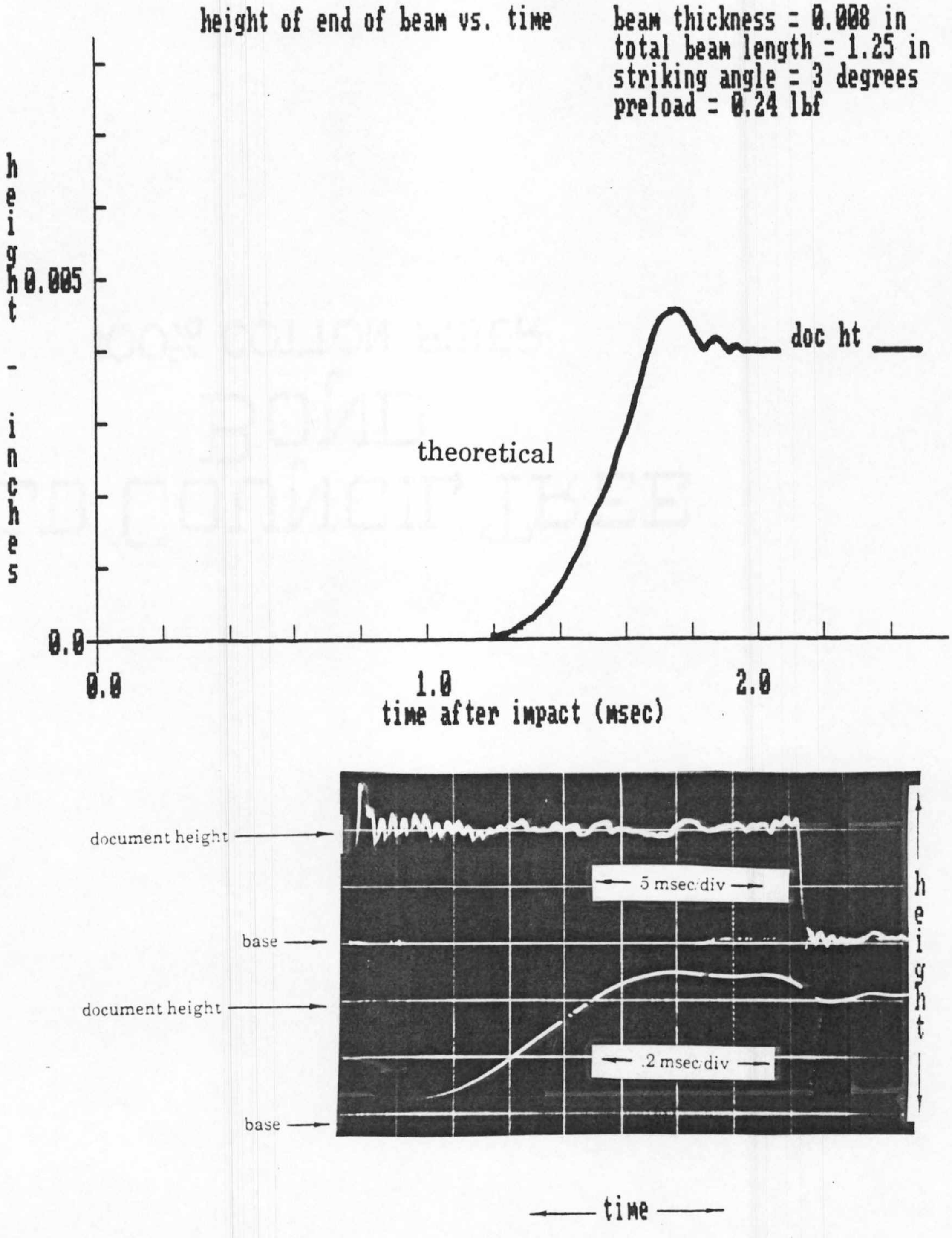
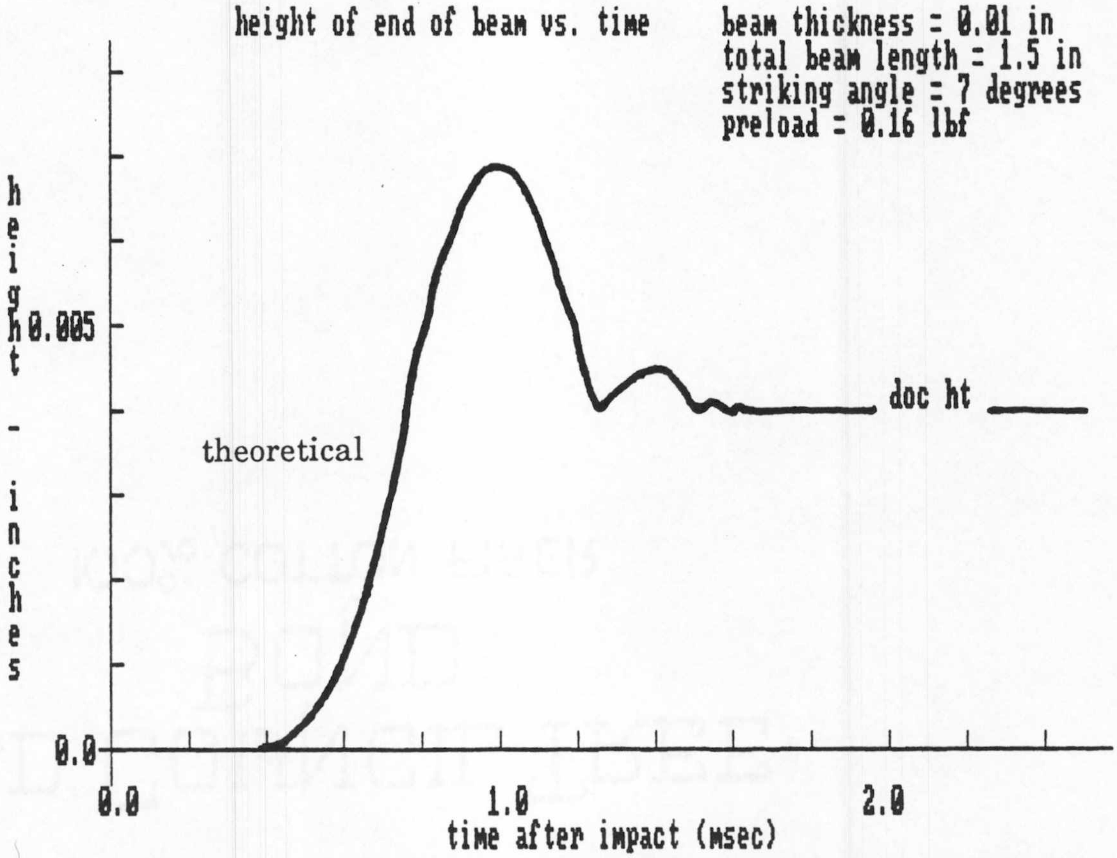


Figure L.1 (continued).



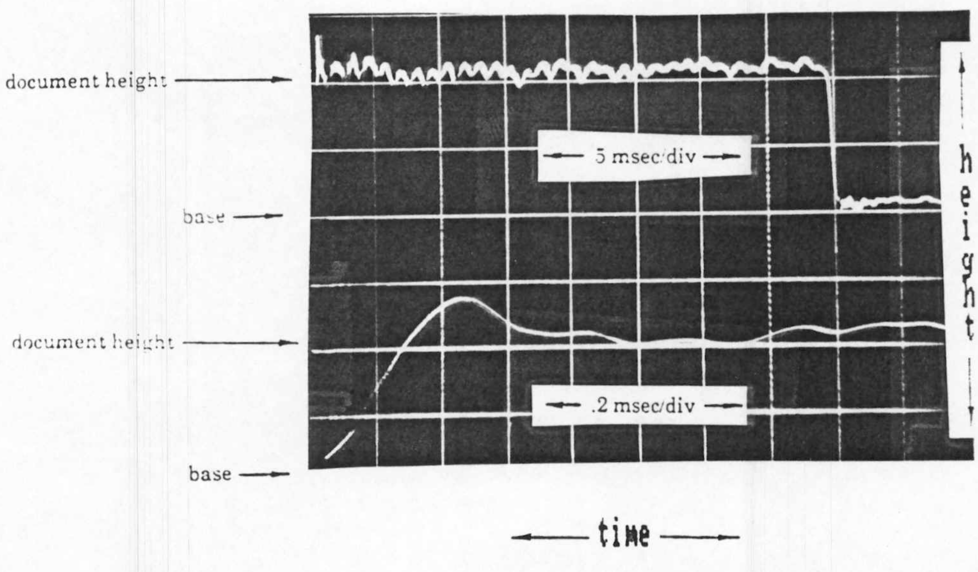


Figure L.1 (continued).

Table L.1. Comparison of theoretical and experimental results.

beam thickness	total beam length	striking angle	preload	% overshoot		rise time to max. height (msec)	
(in)	(in)	(degrees)	(lbf)	theoretical	experimental	theoretical	experimental
0.01	1.75	3	0.16	25	11	0.7	1.1
0.01	1.25	7	0.16	41	46	0.6	0.5
0.012	1.5	7	0.16	36	50	0.6	0.5
0.012	1.5	3	0.16	36	30	0.6	1.0
0.012	1.75	3	0.16	25	25	0.6	0.7
0.008	1.5	7	0.16	41	37	0.6	0.6
0.008	1.5	3	0.16	26	22	0.6	0.9
0.01	1.5	7	0.26	31	29	0.5	0.4
0.01	1.5	3	0.16	26	17	0.6	0.8
0.01	1.25	7	0.32	23	22	0.5	0.5
0.01	1.25	7	0.5	17	33	0.4	0.5
0.008	1.25	3	0.16	22	15	0.6	1.4
0.008	1.25	7	0.26	27	23	0.4	0.5
0.01	1.75	7	0.16	43	15	0.6	1.2
0.01	1.5	7	0.16	42	27	0.6	0.5
0.008	1.25	3	0.24	12	21	0.6	0.7

APPENDIX M

STRESS ANALYSIS

1. INTRODUCTION

Various quantities are required in the stress analysis of the cantilever beam. These will be evaluated throughout.

2. BENDING STRESS ANALYSIS

The bending stress for a cantilever beam is defined as

$$\sigma_{max} = \frac{M_{max} c}{I}$$

where:

c = distance from neutral axis to edge = .011/2

$$I = \frac{wt^3}{12} = \frac{(.5)(.011)^3}{12}$$

$M_{max} = P_{max}$ L

P_{max} was found from the exhaustive computer program for the cantilever beam for a document thickness of 0.1 inch.

P_{max} = .5 lb

M_{max} = (.5) (1.25)

σ_{max} = 61983 psi

The minimum stress of the beam would occur when there are no checks under the detector.

$$\sigma_{min} = \frac{P_{preload} L c}{I}$$

$$\sigma_{min} = \frac{(.27)(1.25)(6)}{(.5)(.011)^2} = 33{,}471\ psi$$

The material used is ASTM A 109 tempered polished feeler gauge stock with a hardness of Rockwell 80B. The yield stress for this material is 65,000 psi. Comparing this to the maximum stress gives a value for the factor of safety (F.S.).

$$F.S. = \frac{\sigma_y}{\sigma_{max}} = 1.05$$

This factor of safety is greater than one, implying that the beam would not fail due to yielding. The fact that the F.S. is very close to one should not be disconcerting, because the assumed model allowed 25 checks to traverse through the machine at once which is highly improbable. Assuming 2 or 3 documents are maximum at one time yields σ_{max} = 37190 psi (F.S. = 1.75).

3. FATIGUE STRESS ANALYSIS

Another means of failure could be due to fatigue in the system. The Soderberg Criterion[2] was used to analyze this mode of failure. As discussed in the text, the maximum stress was assumed to occur when 2.5 documents pass under the beam. This yields the following results.

$$\frac{1}{F.S.} = \frac{\sigma_{mag}}{\sigma_e} + \frac{\sigma_{ave}}{\sigma_y}$$

$$\sigma_{mag} = \frac{\sigma_{max} - \sigma_{min}}{2} = \frac{37190 - 33471}{2} = 1860\, psi$$

$$\sigma_{ave} = \frac{\sigma_{max} + \sigma_{min}}{2} = \frac{37190 + 33471}{2} = 35331\, psi$$

$$\sigma_e = C_f C_r n = (.9)(.71)(32{,}500) = 20768\, psi$$

$$\frac{1}{F.S.} = \frac{1860}{20768} + \frac{35331}{65000}$$

$$F.S. = 1.58$$

Thus, infinite life would be expected for the beam design chosen.

APPENDIX N

EQUIPMENT USED

The following is a list of the equipment used.

oscillosope	Type: Textronix Serial Number: UT 154874 ME 1111
oscilloscope camera	Type: Textronix Serial Number: 012671 UT 131519
proximitor	Type: Bently Nevada Corp., Model 3100N Serial Number: 8508
voltage sources	Type: Bently Nevada Corp. Serial number: UT 189852
	Type: Lambda, Model LL-903 Serial Number: 1931 UT 233932 ME 1181

APPENDIX O

COMPUTER PROGRAMS

Three computer programs were used in analyzing the detector systems. All programs were written in BASIC and programmed and run on personal computers.

The first program written was used to find a spring constant and damping coefficient associated with a particular, given type of document using the equations derived previously from the moment analysis.

The second program evaluates the linear and angular displacements and velocities of discrete mass points on a beam. Transfer matrix analysis was used as well as Runge-Kutta numerical integration.

The last program provides the height of the end of a rigid beam with respect to time after impact by a document.

```
10 LPRINT"number 1 ":LPRINT"******************************************************************
*********"
20 'this program finds a k (spring constant) and a c (damping coefficient)
30 'associated with a particular type of check specifying the initial velocity
40 'of an arm corresponding to a measured experimental value.
50 '      program "Vo"
60 CLS
70  PRINT "calculate the initial velocity of an arm by specifying a
80  PRINT "k and c associated with a particular type of check."
90  PRINT
100  PRINT "for ibm double-feed analysis."
110  PRINT "by david melchers: grad assistant, mech eng, utk
120  PRINT "with frank speckhart: prof, mech eng, utk
130  PRINT "written 9/10/85."
140  PRINT :  PRINT
150 '
160 '           *********** assign constants **********
170 PI=3.1415
180 RA=PI/180      :DEG=180/PI     :RPM=60/(2*PI)     :G=386
190 'assign constants for particular type of beam used for experimentation.
200          L=2                    'beam length (in)
210         WT=.0034                'beam weight w/ no added weight (lb)
220      ADDWT=.0106                'opt. added weight (lb)
230        TFR=.0000375             'frictional torque at pivot (in-lb)
240         VC=145                  'velocity of check (in/sec)
250 '           ********** input variables for specific conditions **********
260 TC=.004
270 PRINT
280 PRINT "input the striking angle betwixt the arm and the document (deg)."
290 INPUT THSTR
300 PRINT
310 THSTR=THSTR*RA
320 PRINT "is there added weight to the arm?
330 PRINT "                                           input
340 PRINT "no added weight --------------------     N
350 PRINT "added weight @ hole # 1 -----------     1
360 PRINT "added weight @ hole # 2 -----------     2
370 INPUT TYPE$
380 IF TYPE$ = "N" THEN I=.000011:YBAR=1.02        'ms mom of inert. (in-lb-s^2)
390 IF TYPE$ = "1" THEN WT=WT+ADDWT:I=.0000501:YBAR=1!
400 IF TYPE$ = "2" THEN WT=WT+ADDWT:I=.0000895:YBAR=.97
410 '
420 PRINT:PRINT"input the type of document to be analyzed (CH or WS)..."
430 INPUT DOC$
440  PRINT "guess a value for k..."
450 INPUT K
460  PRINT "guess a value for c..."
470 INPUT C
480 MARK=0
490 '---------------------------------------------------------------------------
500 'the following constants represent specific constants encountered in the
510 'theoretical analysis of the system and are included to simplify
520 'computations.  refer to the analytic work to determine the nature of the
530 'constants.
540 KK=K*L^2-K*TC*L/SIN(THSTR)
550 CC=C*L^2-C*TC*L/SIN(THSTR)
560 ZETA=CC/(2*SQR(KK*I))
570 C1=K*VC*L*SIN(THSTR)
580 C2=C*VC*L*SIN(THSTR) - TFR - WT*(L-YBAR)*COS(THSTR)
590 C3=CC/(2*I)
600 SQ=C3^2-KK/I
610 IF SQ < 0 THEN SQ=-SQ:PRINT"zeta < 1":MARK=1
```

```
620 C4=SQR(SQ)
630 A0=C1/KK
640 A1=(C2-CC*C1/KK)/KK
650 A =(-A0-A1*(C3+C4))/(2*C4)
660 B =-A1-A
670 IF MARK = 1 THEN A=(-A0-C3*A1)/C4:B=-A1
680 '-----------------------------------------------------------------------
690 '
700 'there are two occurences to check as time increases.
710 '1) has the arm risen above the check thickness?
720 '2) is the spring or damper in tension?
730 '   if so, the arm will no longer be in contact with the check and
740 '   the current value of thetadot should be compared to the exp. measured
750 '   value and k should be corrected.
760 DUM=(L*SIN(THSTR)-TC)/L                  'dummy variable
770 THTC=THSTR-ATN(DUM/SQR(-DUM^2+1))       'theta (rad) at thickness = Tc
780 '
790 '
800 FOR T = 0 TO .0033 STEP .00002
810     E1=EXP(-C3*T)
820     E2=EXP(C4*T)
830     E3=EXP(-C4*T)
840     TR1=SIN(C4*T)
850     TR2=COS(C4*T)
860     TH=E1*(A*E2+B*E3)+A0*T+A1
870     THDOT=E1*(A*C4*E2-B*C4*E3)-C3*E1*(A*E2+B*E3)+A0
880 IF MARK=1 THEN TH=E1*(A*TR1+B*TR2)+A0*T+A1: THDOT=E1*(A*C4*TR2-B*C4*TR1)-C3*
E1*(A*TR1+B*TR2)+A0
890      XXX=L/SIN(THSTR)-TC/(SIN(THSTR)^2)
900      XX1=TH*XXX
910      XX2=THDOT*XXX
920      XXX=VC*T-XX1
930     IF TH > THTC THEN WHY$="theta exceeds thtc":PRINT WHY$:GOTO 980
940     IF VC*T < XX1 THEN WHY$="spring is in tension":PRINT WHY$:GOTO 980
950     IF VC < XX2 THEN WHY$="damper is in tension":PRINT WHY$:GOTO 980
960     IF T > .0032 THEN WHY$="time has exceeded time allowable":PRINT WHY$:GOTO
 980
970 NEXT T
980  PRINT : PRINT USING "K = ####.#### lb/in";K
990  PRINT USING "THETA DOT = ##.# rad/s";THDOT
1000  PRINT USING "ZETA = ##.####";ZETA
1010  PRINT USING "C = #.###### lb-s/in";C
1020  PRINT USING "I = #.## x E-05 in-lb-s^2";I*10^5
1030  PRINT USING "deflection of prototype spring = #.##### in";XXX
1040  PRINT USING "the check left the document because &";WHY$
1050  PRINT USING "time of release = #.##### sec";T
1060  PRINT USING "DOCUMENT TYPE = &";DOC$
1070 PR$="Y"
1080 BEEP:BEEP:BEEP:BEEP:BEEP
1090 IF PR$ = "Y" THEN 1110
1100 GOTO 440
1110 LPRINT:LPRINT USING "K = ####.#### lb/in";K
1120 LPRINT USING"THETA DOT = ##.# rad/s";THDOT
1130 LPRINT USING"ZETA = ##.####";ZETA
1140 LPRINT USING"C = #.###### lb-s/in";C
1150 LPRINT USING"I = #.## x E-05 in-lb-s^2";I*10^5
1160 LPRINT USING"deflection of prototype spring = #.##### in";XXX
1170 LPRINT USING"the check left the document because &";WHY$
1180 LPRINT USING "time of release = #.##### sec";T
1190 LPRINT USING "DOCUMENT TYPE = &";DOC$
1200 GOTO 440
```

```
10 'program "allinone"
20 'created 8-6-85 by david melchers:UT grad student, mech eng dept
30 'for IBM double-feed detector analysis.
40 'with prof frank speckhart
50 'updated 4-1-86 (most recent update)
60 CLS
70  PRINT"@*@*@*@*@*@* pRoGrAm aLlInOnE - dmdmdmdmdmdm @*@*@*@*@*@*@*@*@*@*@"
80 PRINT "this program will proceed through a dynamic analysis of discrete
90 PRINT "masses used to describe a continuous cantilever beam. transfer matrix
100 PRINT "analysis is used as well as numerical integration."  :PRINT:PRINT:PRI
NT:PRINT:PRINT
110 '
120 'set constants to be used in the program.
130 PI=3.1415
140 RA=PI/180   :DEG=180/PI   :RPM=60/(2*PI)   :G=386
150 '
160 '
170  FCT=0:QUIP=0
180  PRINT "there are a variety of capabilities possible with this program.
190  PRINT "refer to the following menu to choose what functions to use.
200  PRINT "-----------------------------------------------------------------
210  PRINT "        (1)  output the height of the end of the beam vs. time to
220  PRINT "             a data file.
230  PRINT "        (2)  change some of the parameters in the program.
240  PRINT "        (3)  produce a hard copy of the dynamic response.
250  PRINT""
260  PRINT " input the function that you wish to use.(enter 1,2,3 or CR for none
)":INPUT FCT
270 PRINT
280  IF FCT=2 THEN CHANGE = 1 :QUIP=1
290  IF FCT=3 THEN HC$="Y":QUIP=1
300  IF FCT <> 1 THEN 370
310       'open a data file. TM = time array,HT = height array.
320       DIM TM(200),HT(200)
330       PRINT "type in the name of the data file.":INPUT FLNM$
340       OPEN FLNM$ FOR OUTPUT AS #1
350       QUIP = 1
360       DTYN=1      'dummy variable
370   IF QUIP = 1 THEN PRINT"what other functions do you wish to use?":GOTO 170
380  IF CHANGE <> 1 THEN CHNG$="N"
390 '
400 '
410 '
420 '          ********** set beam parameters **********
430 '
440           BLEN = 1.5                     ' beam length (in)
450           BWID = .5                      ' beam width (in)
460           BTHK = .01                     ' beam thickness (in)
470           BMOD = 28*10^6                 ' beam mod. of elast. -SS (psi)
480           BRHO = .286                    ' beam density -SS (lb/in^3)
490           MAT$ = "stainless steel"       ' beam material
500 ' "NUM" is the number of discrete masses beyond the fixed end representing
510 ' the continuous system. the runge-kutta analysis will not work if NUM > 20.
520 ' NUM must be > 2
530 NUM = 4
540 LN = 1.5            ' LN is the distance from the pivot to the contact point
550 IF CHNG$ = "N" THEN 790
560 MARK = 0
```

```
570  PRINT USING "total beam length = ##.#### inches."; BLEN
580  PRINT USING "beam width = ##.#### inches."; BWID
590  PRINT USING "beam thickness = ##.#### inches.":BTHK
600  PRINT USING "beam modulus of elasticity = ###.###^^^^ psi."; BMOD
610  PRINT USING "beam density = #.#### lb/in^3."; BRHO
620  PRINT USING "number of discrete mass points = ###.#";NUM
630  PRINT "what parameter do you wish to change?
640  PRINT "                                        enter
650  PRINT "      beam length ---------------- L
660  PRINT "      beam width ----------------- W
670  PRINT "      beam thickness ------------- T
680  PRINT "      beam mod. of elast. -------- E
690  PRINT "      beam density --------------- R
700  PRINT "number of discrete mass points--- N"
710 INPUT CH$
720 IF CH$ = "L" OR CH$ = "l" THEN 4030
730 IF CH$ = "W" OR CH$ = "w" THEN PRINT "enter width.":INPUT BWID :MARK = 1
740 IF CH$ = "T" OR CH$ = "t" THEN PRINT "enter thickness": INPUT BTHK :MARK = 1
750 IF CH$ = "E" OR CH$ = "e" THEN PRINT "enter mod. of elast.": INPUT BMOD :MAR
K = 1
760 IF CH$ = "R" OR CH$ = "r" THEN PRINT "enter density.": INPUT BRHO :MARK = 1
770 IF CH$ = "N" OR CH$ = "n" THEN PRINT "enter # of discrete masses beyond the
fixed end(> 2).":INPUT NUM:MARK=1
780 IF MARK = 1 THEN 560
790 IF HC$ = "Y" THEN 3760
800 '
810 'calculate other beam properties.
820 '
830 BWT = (BLEN*BWID*BTHK)*BRHO                  ' beam weight (lb)
840 BMASS = BWT/G                                ' beam mass (lb-sec^2/in)
850 IA = BWID*BTHK^3/12                          ' beam area mom. of inertia (in^4)
860 EI = BMOD*IA                                 ' beam EI constant (lb-in^2)
870 '
880 '
890 DIM DL(25),L(25),M(25),IM(25),Y(80),UP(200),K(4,80),Z(80),C1(25),C2(25),C3(2
5)
900 ZCHK=0:ARNUM=0:STP=0
910 '
920 '
930 '
940 '          ********** set other system parameters **********
950 '
960            PMAX = .5                          ' max. allow. force on check (lb)
970            PEFF = .1                          ' eff. force on check (lb):preload
980            CTHK = .004                        ' check thickness (in)
990            CVEL = 145                         ' check velocity (in/sec)
1000           THSTR = 10                         ' striking angle of check (deg)
1010              EE = .4                         ' coefficient of restitution
1020              DR = .02                        ' damping ratio
1030 IF CHNG$ = "N" THEN 1250
1040 MARK = 0
1050   PRINT USING "striking angle = ###.### degrees.";THSTR
1060   PRINT USING "effective force on check = ###.### lbs."; PEFF
1070   PRINT USING "coefficient of restitution = .### ";EE
1080  PRINT USING "damping ratio = .###### ";DR
1090  PRINT USING "check thickness = .###### inches";CTHK
1100  PRINT
1110  PRINT "what parameter do you wish to change?
1120  PRINT "                                        enter
1130  PRINT "      effective force on check ----- P
1140  PRINT "      striking angle of check ------ S
1150  PRINT "      coeff of restitution --------- E
1160  PRINT "      damping ratio ---------------- D
1170  PRINT "      check thickness -------------- T"
1180 INPUT CH$
```

```
1190 IF CH$ = "P" OR CH$ = "p" THEN PRINT "enter the desired effective force on
the check.":INPUT PEFF:MARK=1
1200 IF CH$ = "S" OR CH$ = "s" THEN PRINT "enter new striking ang. of check (in
deg).":INPUT THSTR:MARK=1
1210 IF CH$ = "E" OR CH$ = "e" THEN PRINT "enter the new coeff. of restitution."
: INPUT EE:MARK=1
1220 IF CH$ = "D" OR CH$ = "d" THEN PRINT "enter the new damping ratio.": INPUT
DR: MARK=1
1230 IF CH$ = "T" OR CH$ = "t" THEN PRINT "enter the new check thickness.":INPUT
 CTHK:MARK=1
1240 IF MARK = 1 THEN 1040
1250 THSTR = THSTR*RA
1260 ' note: since the solution for the cantilever beam  has axes parallel and
1270 ' perpendicular to the angle of the imbedded end of the beam, the axes
1280 ' must be translated and rotated to find the position along the horiz.
1290 ' and vert.
1300 'solve for P (where P is the force perpendicular to the imbedded end of the
1310 'beam required to cause the beam to take the shape such that Peff as given
1320 'above is the initial force on the check) and the effective beam axis
1330 'rotation to obtain the initial conditions of the beam in x-y coordinates
1340 'horizontal and vertical.
1350 '
1360 PSTART=PEFF:PSTEP=PEFF/100
1370 N=0:NN=0:UP(0)=0
1380 PFIND=PSTART-PSTEP
1390 'begin loop
1400 '
1410 PFIND=PFIND+PSTEP
1420 PRINT USING"PFIND=##.##### UP(N)=##.#########";PFIND,UP(N)
1430 N=N+1
1440 THROT = PFIND*LN^2/(2*EI)+THSTR
1450 UP(N)=ABS(PFIND-PEFF/COS(THROT))
1460 IF UP(N) > UP(N-1) THEN NN=NN+1
1470 IF NN > 1 THEN NN=1:PSTART=PFIND-2*PSTEP:PSTEP=-PSTEP/2
1480 IF UP(N) < .000001 THEN P=PFIND:GOTO 1510
1490 GOTO 1410
1500 '
1510  PRINT USING " preload = ###.##### lbs   throt = ##.### deg";P,THROT*DEG
1520  PRINT:PRINT
1530 IF CHNG$="N" THEN 1560
1540 PRINT "do you want to change any variables?  if so, type Y":INPUT QUES$
1550 IF QUES$="Y" THEN THSTR=THSTR*DEG:GOTO 1040
1560 IF HC$ = "Y" THEN 3860
1570 '
1580 'YMAX is the y-distance at the tip of the beam when force P is applied.
1590 YMAX = P*LN^3/(3*EI)
1600 '**** check max P on check for system with Pmax allowable. ******
1610 'the maximum possible thickness passing under the check is given as 0.1 in.
1620 YCHECK=YMAX + .1*COS(THROT)
1630 PCHECK=3*EI*YCHECK/(LN^3)*COS(THROT)
1640 IF PCHECK > PMAX THEN 4290
1650 '          ********** find the location of the mass points **********
1660 'there will be a mass point at the contact point
1670 'and NUM - 1 masses at equal intervals previous to the
1680 'mass point at the contact point. Also there will be a "dead" mass
1690 'point at the imbedded end of the beam.
1700 MPERL = BMASS/BLEN                             'mass per length
1710 'establish four arrays where:
1720 '     DL IS THE LENGTH OF THE BEAM ASSOCIATED WITH EACH MASS POINT
1730 '     L  IS THE DISTANCE FROM THE IMBEDDED END OF EACH MASS POINT
1740 '     M  IS THE DISCRETE MASS
1750 '     IM IS THE MASS MOMENT OF INERTIA OF EACH SECTION
```

```
1760 DL(0)=LN/(2*NUM)
1770 L(0)=0
1780 FOR I = 1 TO NUM-1
1790    DL(I)=2*DL(0)
1800 NEXT I
1810 DL(NUM)=DL(0)+(BLEN-LN)
1820 FOR I = 1 TO NUM
1830    L(I)=L(I-1)+2*DL(0)
1840    M(I)=DL(I)*MPERL
1850    IM(I)=M(I)/12*(BTHK^2+DL(I)^2)
1860 NEXT I
1870  PRINT: PRINT "to solve the dynamics of this system, the documents striking
1880  PRINT "the detector will be modeled as a rigid beam with constant velocity
1890  PRINT "with a spring/damper included to model the deformation of the
1900  PRINT "document.  The values for the spring constant and damping ratio of
1910  PRINT "specific documents must be determined experimentally.
1920 SC=30:DC=.0001:GOTO 1970      'NOTE: these are evaluated constants.
1930  PRINT: PRINT "Input a reasonable value for the spring constant(approx 30 l
b/in)"
1940 INPUT SC
1950  PRINT: PRINT "Input a reasonable value for the damping coeff(approx .0001
lb-sec/in)"
1960 INPUT DC
1970 PRINT USING "spring constant = ####.## lb/in  damping coefficient = #.#####
# lb-sec/in";SC,DC
1980 '
1990 '
2000 '
2010 '            ********** set initial conditions of beam **********
2020 '
2030 FOR I=1 TO 80
2040     Y(I)=0
2050 NEXT I                'set all initial conditions equal to zero
2060 'since the beam has been modeled with axes perpendicular and parallel to
2070 'the imbedded end of the beam, all of the dynamic analysis will be done
2080 'with respect to these axes.  then the coordinates will be rotated and
2090 'translated to give the response of the beam in a horizontal - vertical
2100 'system.
2110 'the matrix Y below contains the following dynamic parameters:
2120 '                        y, ydot, theta, thetadot
2130 FOR I=0 TO NUM
2140     Y(4*I+2)=0                    'ydot for all masses = 0
2150     Y(4*I+4)=0                    'thetadot for all masses = 0
2160 NEXT I
2170 Y(1)=0                            'y of mass zero = 0
2180 Y(3)=0                            'theta of mass zero = 0
2190 Y(4*NUM+1)=YMAX                   'y at end of beam
2200 Y(4*NUM+3)=P*LN^2/(2*EI)          'theta at end of beam
2210 FOR I = 0 TO NUM
2220    LL=LN-L(I)                      'LL is the distance from the free end
2230    Y(4*I+1)=P/(6*EI)*(LL^3-3*LN^2*LL+2*LN^3)    'y of mass I
2240    Y(4*I+3)=P/(2*EI)*(LN^2-LL^2)                'theta of mass I
2250 NEXT I
2260 '           ********** force analysis **********
2270 ' Initially the transport base exerts a normal force equal to P*cos(THrot)
2280 ' If the document strikes the detector arm at some time,t=0, the normal
2290 ' force that the transport base exerts on the detector will decrease as the
2360 ' document impact force begins to raise the detector arm off the transport
2370 ' base.  eventually, at some time, t=to, the normal force will vanish and
2300 ' for t=to+ the detector will begin to raise.  Thus, solve for to and begin
2310 ' runge-kutta analysis a little bit before this time.
2320 '
```

```
2330 '          ********** solve for to **********
2340 ' At t=to the document force perpendicular to the undeformed beam
2350 ' is simply equal to P.
2360 TO=(P/(SIN(THROT)*SIN(THSTR)*COS(THSTR))-DC*CVEL)/(SC*CVEL)
2370 PRINT USING"the approx. time for the detector to leave the trans. base is #
#.### msec";TO*1000
2380 IF HC$="Y" THEN LPRINT USING"the approx. time for the detector to leave the
 trans. base is ##.### msec";TO*1000
2390 IF CHNG$="N" THEN T=0:GOTO 2440
2400 PRINT"at what time (in msec) do you wish to start the runge-kutta analysis?
"
2410 PRINT"if unknown, type ZERO (0)"
2420 INPUT T
2430 T=T/1000
2440 FOR III=1 TO NUM                        'set constants to be used in runge-kutta
2450     C1(III)=12*EI/DL(III)^3
2460     C2(III)=6*EI/DL(III)^2
2470     C3(III)=2*EI/DL(III)
2480 NEXT III
2490 C1(0)=C1(1):C2(0)=C2(1):C3(0)=C3(1)
2500 DHK=0
2510 '
2520 '
2530 '
2540 '          ********** begin runge-kutta analysis **********
2550 '
2560 'i will evaluate the y and theta values for the non-rotated and
2570 'non-translated system and then translate and rotate before i print.
2580 REM t9 = maximum time
2590 T9=.01
2600 REM t8 is equal to the print interval
2610 T8=.00002
2620 REM d1 = increment of integration step size
2630 D1 =.00002
2640  PRINT:TIMARK = 0
2650  PRINT USING " the integration step size is ##.##^^^^ sec.";D1
2660  PRINT USING " the print interval is ##.##^^^^ sec. ";T8
2670  PRINT USING " this is equivalent to every ###.# integration(s).";T8/D1
2680  PRINT USING " the maximum time for printing is ##.##^^^^ sec. ";T9
2690  PRINT USING " #####.## trials will be printed.";T9/T8
2700  PRINT "do you wish to change any of these parameters?
2710  PRINT "                                    enter
2720  PRINT "  integration step size? -------------- I
2730  PRINT "  print interval? --------------------- P
2740  PRINT "  maximum time for printing? ---------- M "
2750 INPUT TIMECH$
2760 IF TIMECH$ = "I" OR TIMECH$ = "i" THEN PRINT"input integration step size:":
INPUT D1:TIMARK=1
2770 IF TIMECH$ = "P" OR TIMECH$ = "p" THEN PRINT"input print interval:":INPUT T
8:TIMARK=1
2780 IF TIMECH$ = "M" OR TIMECH$ = "m" THEN PRINT"input maximum time:":INPUT T9:
TIMARK=1
2790 IF TIMARK = 1 THEN 2640
2800 CLS
2810 T8 = T8/D1
2820 IF HC$ = "Y" THEN 3910
2830 REM n = number of first order equations for runge-kutta.
2840 N = 4*(NUM+1)
2850        FOR I=1 TO 80
2860           Z(I) = Y(I)
2870        NEXT I
2880 T7 = 9.000001E+09
2890 GOTO 3290
2900 '
```

```
2910         FOR J=1 TO 4
2920            ON J GOTO 3070,2930,2980,3020
2930            T = T+D1*.5
2940               FOR I=1 TO N
2950                  Y(I) = K(1,I)*D1*.5 + Z(I)
2960               NEXT I
2970            GOTO 3070
2980               FOR I=1 TO N
2990                  Y(I) = K(2,I)*D1*.5 + Z(I)
3000               NEXT I
3010            GOTO 3070
3020            T = T+.5*D1
3030               FOR I=1 TO N
3040                  Y(I) = K(3,I)*D1 + Z(I)
3050               NEXT I
3060 '
3070 '            ********** first order equations **********
3080 '
3090 'define a K matrix where K(x,y) is the derivative of Y(y)
3100 QQ=0:MM=2
3110 FOR Q=1 TO N
3120 K(J,Q)=Y(Q+1)
3130 IF Q=MM+4 THEN 4760
3140 IF Q=MM+6 THEN 4810
3150 IF Q <= 4 THEN K(J,Q)=0
3160 IF Q=N-2 THEN 4860
3170 IF Q=N   THEN 4890
3180 NEXT Q
3190     Y(4*NUM+1) = Y(4*NUM+1) - YMAX              'translate coordinate
3200     Y(4*NUM+1) =Y(4*NUM+1)*COS(ABS(THROT))+L(0)*SIN((THROT))    'rotate coord
inate
3210 IF Y(4*NUM+1) > CTHK + .000001 THEN ZCHK=1
3220     Y(4*NUM+1) =(Y(4*NUM+1)-L(NUM-NUM)*SIN(THROT))/COS(THROT)   'unrotate
3230     Y(4*NUM+1) = Y(4*NUM+1) + YMAX           'untranslate coordinate
3240 IF ZCHK=0 THEN 4560
3250         NEXT J
3260         FOR I=1 TO N
3270            Z(I)=Z(I)+D1*(K(1,I)+K(4,I)+2*(K(3,I)+K(2,I)))/6
3280         NEXT I
3290         FOR I=1 TO N
3300            Y(I) = Z(I)
3310         NEXT I
3320 T7=T7+1
3330 IF T7 <= T8-.0002 THEN 3690
3340 T7 = 0
3350 '
3360 '            *********** print results ***********
3370 '
3380 FOR K=NUM TO 0 STEP -1
3390     Y(4*K+1) = Y(4*K+1) - YMAX            'translate coordinates
3400     Y(4*K+1) =Y(4*K+1)*COS(ABS(THROT))+L(NUM-K)*SIN((THROT))    'rotate coord
inates
3410   Y(4*K+3) = Y(4*K+3) - THROT        'rotate coordinates
3420 NEXT K
3430 IF Y(4*NUM+1) < CTHK AND ZCHK=1 THEN 4360
3440 IF HC$ = "Y" THEN GOTO 3960
3450  PRINT:PRINT:PRINT USING"T=###.### msec.";(T+TIME)*1000
3460  PRINT" ** dist along ** height ** velocity **  theta  **thetadot **
3470  PRINT" ** undeformed **   (in)  ** (in/sec) **  (deg)  **(rad/sec)**
3480  PRINT" ** beam (in)  **         **          **         **         **
3490  PRINT"-----------------------------------------------------------"
3500 IF DTYN <> 1 THEN 3540
```

```
3510 'output to data file the height of end of beam vs. time.
3520 ARNUM=ARNUM+1:TM(ARNUM)=(T+TIME)*1000:HT(ARNUM)=Y(N-3)
3530 PRINT #1,TM(ARNUM),HT(ARNUM)
3540 XYZ=0
3550 FOR II=N TO 4 STEP -4
3560 IF HC$ = "Y" THEN 4010
3570  PRINT USING" ####.####  ";L(NUM-XYZ),Y(II-3),Y(II-2),Y(II-1)*DEG,Y(II)
3580 XYZ=XYZ+1
3590 NEXT II
3600 IF DHK=1 AND HC$="Y" THEN LPRINT:LPRINT"the detector is now off the base":L
PRINT
3610 FOR K=NUM TO 0 STEP -1
3620    Y(4*K+1) =(Y(4*K+1)-L(NUM-K)*SIN(THROT))/COS(THROT)  'unrotate
3630    Y(4*K+1) = Y(4*K+1) + YMAX                'untranslate coordinates
3640    Y(4*K+3) = Y(4*K+3) + THROT    'unrotate coordinates
3650 NEXT K
3660 IF HC$ = "Y" THEN 3990
3670  PRINT"*************************************************************"
3680  PRINT
3690 IF T= < T9 THEN 2900
3700 END
3710 '
3720 '
3730 '
3740 '          *********** **********
3750 '
3760 LPRINT "DYNAMIC ANALYSIS OF MASS POINTS ON A CANTILEVER BEAM"
3770 LPRINT "---------------------------------------------------"
3780 LPRINT MAT$
3790 LPRINT USING"total beam length = ##.#### inches."; BLEN
3800 LPRINT USING"beam width = ##.#### inches."; BWID
3810 LPRINT USING"beam thickness = ##.###### inches."; BTHK
3820 LPRINT USING "beam modulus of elasticity = ###.###^^^^ psi."; BMOD
3830 LPRINT USING"beam density = #.#### lb/in^3."; BRHO
3840 LPRINT:LPRINT
3850 GOTO 800
3860 LPRINT USING "perpendicular preload = ###.###### lbs."; P
3870 LPRINT USING "effective preload = ###.###### lbs."; PEFF
3880 LPRINT USING"striking angle = ###.### degrees.";THSTR*DEG
3890 LPRINT:LPRINT
3900 GOTO 1570
3910 LPRINT" ** dist along ** height ** velocity **  theta  **thetadot **
3920 LPRINT" ** undeformed **   (in)  ** (in/sec) **  (deg)  **(rad/sec)**
3930 LPRINT" ** beam (in)  **         **          **         **          **
3940 LPRINT"-------------------------------------------------------------"
3950 GOTO 2830
3960  LPRINT USING"T=###.### msec.";(T+TIME)*1000
3970 LPRINT" "
3980 GOTO 3500
3990 LPRINT"*************************************************************"
4000 GOTO 3690
4010 LPRINT USING" ####.####  ";L(NUM-XYZ),Y(II-3),Y(II-2),Y(II-1)*DEG,Y(II)
4020 GOTO 3580
```

```
4030 PRINT "recognize that to change the length of the beam two factors are invo
lved.
4040 PRINT "the end of the beam may be curved up to decrease the striking angle.
4050 PRINT "therefore two lengths are required to sufficiently describe the syst
em.
4060 PRINT "one is the total length of the cantilever beam.
4070 PRINT "the other is the length from the pivot point to where the beam rests
 on the base of the machine."
4080 PRINT:PRINT
4090 PRINT "enter the new value for total beam length.": INPUT BLEN
4100 PRINT:PRINT
4110 PRINT "enter the new value for the distance from the pivot point to the con
tact point."
4120 INPUT LN
4130 MARK = 1
4140 GOTO 780
4150 IF CHK=1 THEN 4170
4160 GOTO 3430
4170 IF HMAX <= CTHK+.002 THEN 4190
4180 GOTO 3430
4190  IF HC$="Y" THEN LPRINT"the detector is within the height limit."
4200  IF HC$="Y" THEN LPRINT USING"settling time = ####.###### sec.";T
4210  PRINT"the detector is within the height limit."
4220  PRINT USING"settling time = ####.###### sec.";T
4230 END
4240 IF RKHK = 0 THEN 3440
4250 CHK=0
4260 Y(4*NUM+4)=-Y(4*NUM+4)*EE
4270 Y(4*NUM+2)=-Y(4*NUM+2)*EE     'thetadot and ydot at end change on bounces.
4280 GOTO 3440
4290  IF HC$="Y" THEN LPRINT "P is greater than Pmax for cthk=.1 ."
4300  IF HC$="Y" THEN LPRINT "this system will not satisfy the constraints."
4310  IF HC$="Y" THEN LPRINT USING "pmax for cthk =.1 is #####.####.";PCHECK
4320  PRINT "P is greater than Pmax for cthk=.1 ."
4330  PRINT "this system will not satisfy the constraints."
4340  PRINT USING "pmax for cthk =.1 is #####.####.";PCHECK
4350  GOTO 1650
4360 PRINT"detector arm strikes document"
4370 STP=STP+1
4380 IF STP < 7 THEN 4410
4390 IF DTYN = 1 THEN CLOSE 1:GOTO 4920
4400 GOTO 4920
4410 Y(4*NUM+2)=-EE*Y(4*NUM+2)
4420 Y(4*NUM+4)=-EE*Y(4*NUM+4)
4430 Y(4*NUM+1)=CTHK + .000004
4440 FOR K=NUM TO 0 STEP -1
4450     Y(4*K+1) =(Y(4*K+1)-L(NUM-K)*SIN(THROT))/COS(THROT)   'unrotate
4460     Y(4*K+1) = Y(4*K+1) + YMAX              'untranslate coordinates
4470     Y(4*K+3) = Y(4*K+3) + THROT     'unrotate coordinates
4480 NEXT K
4490 TIME = TIME+T
4500 T=0
4510 FOR II=1 TO 80
4520  Z(II)=Y(II)
4530 NEXT II
4540 T7 = 9.000001E+09
4550 GOTO 3290
4560     Y(4*NUM+1) = Y(4*NUM+1) - YMAX              'translate coordinate
4570     Y(4*NUM+1) =Y(4*NUM+1)*COS(ABS(THROT))+L(0)*SIN((THROT))    'rotate coord
inate
4580    Y(4*NUM+3) = Y(4*NUM+3) - THROT        'rotate coordinate
4590    K1=Y(4*NUM+1)         'y @ num
4600    K2=Y(4*NUM+2)         'ydot @ num
4610    K3=Y(4*NUM+3)         'theta @ num
4620    K4=Y(4*NUM+4)         'thetadot @ num
4630    K5=M(NUM)            'mass of num
```

```
4640 'ADOC is the acceleration due to the document force.
4650 ADOC=SC/K5*(CVEL*T-K1*TAN(ABS(K3)))+DC/K5*(CVEL-(K2*TAN(ABS(K3))+K1/(COS(AE
S(K3)))^2))  'accel. of mass pt. in dir. of document motion.
4660     Y(4*NUM+1) =(Y(4*NUM+1)-L(NUM-NUM)*SIN(THROT))/COS(THROT)   'unrotate
4670     Y(4*NUM+1)  = Y(4*NUM+1) + YMAX           'untranslate coordinate
4680     Y(4*NUM+3)  = Y(4*NUM+3) + THROT     'unrotate coordinate
4690 ADY = ADOC*SIN(ABS(K3))*COS(ABS(K3))   'doc. accel. in y-direction.
4700 PY = P*COS(ABS(THROT))*COS(ABS(K3))    'bending force in y-direction.
4710 PRINT USING"vert. force on beam from doc. contact = #.####   vert. force fr
om beam = #.####";ADY*K5,PY
4720 IF ADY*K5 > PY THEN PRINT"stage 2:document in contact,arm off base":K(J,N-2
)=K(J,N-2)+ADY:DHK=DHK+1:GOTO 3250
4730 K(J,N-2)=0
4740 PRINT"stage 1:document in contact, arm on base"
4750 GOTO 3250
4760 QQ=QQ+1
4770 VIR=C1(QQ)*(Y(Q+3)-Y(Q-1))-C2(QQ)*(Y(Q+5)+Y(Q+1))
4780 VIL=C1(QQ-1)*(Y(Q-1)-Y(Q-5))-C2(QQ-1)*(Y(Q+1)+Y(Q-3))
4790 K(J,Q)=(VIR-VIL)/M(CINT((Q-2)/4))
4800 GOTO 3140
4810 MM=MM+4
4820 MIR=C2(QQ)*(Y(Q+1)-Y(Q-3))-C3(QQ)*(Y(Q+3)+2*Y(Q-1))
4830 MIL=-C2(QQ-1)*(Y(Q-3)-Y(Q-7))+C3(QQ-1)*(2*Y(Q-1)+Y(Q-5))
4840 K(J,Q)=(MIR-MIL)/IM(CINT((Q-4)/4))
4850 GOTO 3150
4860 VIL=C1(QQ-1)*(Y(Q-1)-Y(Q-5))-C2(QQ-1)*(Y(Q+1)+Y(Q-3))
4870 K(J,Q)=-VIL/M(CINT((Q-2)/4))
4880 GOTO 3170
4890 MIL=-C2(QQ-1)*(Y(Q-3)-Y(Q-7))+C3(QQ-1)*(2*Y(Q-1)+Y(Q-5))
4900 K(J,Q)=-MIL/IM(CINT((Q-4)/4))
4910 GOTO 3180
4920  FOR ZIZI=1 TO 2000 STEP 10
4930  IZIZ=INT(RND*ZIZI)
4940  SOUND IZIZ, .25
4950  NEXT ZIZI
4960 IF DTYN <> 1 THEN END
4970 PRINT"check your data."
4980 PRINT"press CR to continue"
4990 INPUT ANY
5000 IF DTYN=1 THEN 5020
5010 INPUT "from what file do you wish the data to be listed";FLNM$
5020 OPEN FLNM$ FOR INPUT AS #1
5030 IF EOF(1) THEN END
5040 INPUT #1,A,B
5050 PRINT USING" ##.### MSEC  #.###### INCHES";A,B
5060 GOTO 5030
```

```
10 ' ****************************************************************************
20 ' ************************* program "rigrep" *************************
30 '
40 'program "rigid"
50 'created 3-14-85 by david melchers:UT grad student, mech eng dept
60 'for IBM double-feed detector analysis.
70 'with prof frank speckhart
80 'updated 5-28-86 (most recent update)
90 CLS
100  PRINT"@*@*@*@*@*@* pRoGrAm rIgId - dmdmdmdmdmdm @*@*@*@*@*@*@*@*@*@"
110 PRINT "this program will proceed through a dynamic analysis of a rigid
120 PRINT "beam (with a spring at the support) that is struck by a variety of
130 PRINT "document types."  :PRINT:PRINT:PRINT:PRINT:PRINT
140 '
150 'set constants to be used in the program.
160 PI=3.141593
170 RA=PI/180    :DEG=180/PI    :RPM=60/(2*PI)    :G=386
180 '
190 '
200  FCT=0:DUM2=0
210  PRINT "there are a variety of capabilities possible with this program.
220  PRINT "refer to the following menu to choose what functions to use.
230  PRINT "-----------------------------------------------------------------
240  PRINT "        (1)  output the height of the end of the beam vs. time to
250  PRINT "             a data file.
260  PRINT "        (2)  change some of the parameters in the program.
270  PRINT "        (3)  produce a hard copy of the dynamic response.
280  PRINT""
290  PRINT " input the function that you wish to use.":INPUT FCT
300  IF FCT=2 THEN CHANGE = 1 :DUM2=1
310  IF FCT=3 THEN HC$="Y":DUM2=1
320  IF FCT <> 1 THEN 390
330       'open a data file. TM = time array,HT = height array.
340       DIM TM(200),HT(200)
350       PRINT "type in the name of the data file.":INPUT FLNM$
360       OPEN FLNM$ FOR OUTPUT AS #1
370       DUM2 = 1
380       DTYN=1       'dummy variable
390  IF DUM2 = 1 THEN PRINT"what other functions do you wish to use?":GOTO 200
400  IF CHANGE <> 1 THEN CHNG$="N"
410 '
420 '
430 ' ****************************************************************************
440 ' ******************* set beam parameters ******************************
450 '
460           LUP = 1.75            ' distance to first bend in beam(in)
470           LLO = .05             ' dist. from bend to end of beam(in)
480          BWID = .1              ' beam width (in)
490          BTHK = .1              ' beam thickness (in)
500          BMOD = 10*10^6         ' beam mod. of elast. -SS (psi)
510          BRHO = .1             ' beam density -SS (lb/in^3)
520          MAT$ = "aluminum"      ' beam material
530          BLEN = LLO+LUP         ' total beam length (in)
540          PMAX = .5              ' max. allow. force on check (lb)
550         TPEFF = 1'             ' eff mom on doc desired(in-lb):preload
560          CTHK = .004            ' check thickness (in)
570          CVEL = 145             ' check velocity (in/sec)
580         THSTR = 2.5             ' striking angle of check (deg)
590        THBEND = 160             ' angle of bend in beam (deg)
600        KTHETA =  .5             ' torsional spring constant (in-lb)
610            EE = .4              ' coefficient of restitution
620            DR = .02             ' damping ratio
630 MARK = 0
```

```
640 BLEN=LUP+LLO
650  PRINT USING "total beam length = ##.#### inches."; BLEN
660  PRINT USING "dist. from bend to end of beam = ##.#### inches."; LLO
670  PRINT USING "distance to first bend in beam = ##.#### inches."; LUP
680  PRINT USING "beam width = ##.#### inches."; BWID
690  PRINT USING "beam thickness = ##.#### inches.";BTHK
700  PRINT USING "beam modulus of elasticity = ###.###^^^^ psi."; BMOD
710  PRINT USING "beam density = #.#### lb/in^3."; BRHO
720  PRINT USING "striking angle = ###.### degrees.";THSTR
730  PRINT USING "angle of bend = ###.### degrees.";THBEND
740  PRINT USING "effective moment on check = ###.### in-lb";TPEFF
750  PRINT USING "coefficient of restitution = .### ";EE
760  PRINT USING "torsional spring constant = ##.#### in-lb";KTHETA
770  PRINT USING "damping ratio = .###### ";DR
780  PRINT USING "check thickness = .###### inches";CTHK
790 IF CHNG$ = "N" THEN 1040
800  PRINT "what parameter do you wish to change?
810  PRINT "                               enter                                    enter
820  PRINT " dist. from bend to end  -- L      striking angle of check ---- S
830  PRINT " distance to first bend  -- U      bend angle in rigid beam --- B
840  PRINT " beam width --------------- W      coeff. of restitution ------ E
850  PRINT " beam thickness ----------- T      torsional spring constant -- K
860  PRINT " beam mod. of elast. ------ M      damping ratio -------------- D
870  PRINT " beam density ------------- R      check thickness ------------ C
880  PRINT " eff. moment on check ----- P"
890 INPUT CH$
900 IF CH$ = "U" OR CH$ ="u" THEN PRINT"enter upper length.":INPUT LUP :MARK=1
910 IF CH$ = "L" OR CH$ ="l" THEN PRINT"enter lower length.":INPUT LLO :MARK=1
920 IF CH$ = "W" OR CH$ ="w" THEN PRINT "enter width.":INPUT BWID :MARK = 1
930 IF CH$ = "T" OR CH$ ="t" THEN PRINT "enter thickness": INPUT BTHK :MARK = 1
940 IF CH$ = "M" OR CH$ ="m" THEN PRINT "enter mod. of elast.": INPUT BMOD :MARK
 = 1
950 IF CH$ = "R" OR CH$ ="r" THEN PRINT "enter density.": INPUT BRHO :MARK = 1
960 IF CH$ = "P" OR CH$ ="p" THEN PRINT "enter the desired effective moment on t
he check.":INPUT TPEFF:MARK=1
970 IF CH$ = "S" OR CH$ ="s" THEN PRINT "enter new striking ang. of check (in de
g).":INPUT THSTR:MARK=1
980 IF CH$ = "B" OR CH$ ="b" THEN PRINT "enter angle of bend in beam (in deg).":
INPUT THBEND:MARK=1
990 IF CH$ = "E" OR CH$ ="e" THEN PRINT "enter the new coeff. of restitution.":
INPUT EE:MARK=1
1000 IF CH$ = "K" OR CH$ ="k" THEN PRINT "enter the new torsional spring constan
t.": INPUT KTHETA:MARK=1
1010 IF CH$ = "D" OR CH$ ="d" THEN PRINT "enter the new damping ratio.": INPUT D
R: MARK=1
1020 IF CH$ = "C" OR CH$ ="c" THEN PRINT "enter the new check thickness.":INPUT
CTHK:MARK=1
1030 IF MARK = 1 THEN 630
1040 IF HC$ <> "Y" THEN 1200                   'skip over hc section?
1050 LPRINT USING "total beam length = ##.#### inches."; BLEN
1060 LPRINT USING "dist. from bend to end of beam = ##.#### inches."; LLO
1070 LPRINT USING "distance to first bend in beam = ##.#### inches."; LUP
1080 LPRINT USING "beam width = ##.#### inches."; BWID
1090 LPRINT USING "beam thickness = ##.#### inches.";BTHK
1100 LPRINT USING "beam modulus of elasticity = ###.###^^^^ psi."; BMOD
1110 LPRINT USING "beam density = #.#### lb/in^3."; BRHO
1120 LPRINT USING "striking angle = ###.### degrees.";THSTR
1130 LPRINT USING "angle of bend = ###.### degrees.";THBEND
1140 LPRINT USING "effective moment on check = ###.### in-lb";TPEFF
1150 LPRINT USING "coefficient of restitution = .### ";EE
1160 LPRINT USING "torsional spring constant = ##.#### in-lb";KTHETA
1170 LPRINT USING "damping ratio = .###### ";DR
1180 LPRINT USING "check thickness = .###### inches";CTHK
1190 LPRINT:LPRINT
1191 III=3
1200 '
```

```
1210 ' ***************************************************************************
1220 ' ************** calculate other beam properties *************************
1230 '
1240 BWT = (BLEN*BWID*BTHK)*BRHO            ' beam weight (lb)
1250 BMASS = BWT/G                          ' beam mass (lb-sec^2/in)
1260 MPERL=BMASS/BLEN                       ' beam mass per length (lb-sec^2/in^2)
1270 MUP=MPERL*LUP                          ' mass of upper portion of beam
1280 MLO=MPERL*LLO                          ' mass of lower portion of beam
1290 THSTR=THSTR*RA:THBEND=THBEND*RA        ' change angles to radians
1300 LSTR=((LUP)^2+(LLO-CTHK/SIN(THSTR))^2-2*LUP*(LLO-CTHK/SIN(THSTR))*COS(THBEN
D))^.5          'distance from pivot to where the document strikes the beam (in)
1310 LCOG=(LUP^2+(LLO/2)^2-2*LUP*(LLO/2)*COS(THBEND))^.5
1320       'lcog is the dist. from the pivot to the cog of the lower beam portio
1330 IM=MUP*LUP^2/3+MLO*LLO^2/12+MLO*LCOG^2  'mass moment of inertia(in-lb-s^2)
1340 DUM3=LUP*SIN(THBEND)/LSTR
1350 THCHK=ATN(DUM3/SQR(-DUM3^2+1))         'interior angle
1360 THLO=PI/2-THCHK-THSTR                  'angle of initial motion
1370 THUP = PI-(THBEND-THSTR)               'angle of upper arm wrt horizontal
1380 HTOT = LUP*SIN(THUP)+LLO*SIN(THSTR)    'vert. dist. from base to pivot (in)
1390 K=KTHETA/IM                            '************** constants
1400 CTHETA=2*DR*SQR(KTHETA*IM)             '               for
1410 C=CTHETA/IM                            '               subsequent
1420 OMEGA=SQR(K-C^2/4)                     '               analysis
1430 LBASE=SQR(LSTR^2+(CTHK/SIN(THSTR))^2+2*LSTR*CTHK/SIN(THSTR)*COS(THCHK))
1440 DUM4=(HTOT-CTHK)/LBASE
1450 DUM5=LUP*SIN(THBEND)/LBASE
1460 ALPHA = ATN(DUM5/SQR(-DUM5^2+1))
1470 THCT=ALPHA +THSTR-ATN(DUM4/SQR(-DUM4^2+1))
1480                       ' thct: theta required for arm to reach check height
1490 DUM6=(HTOT-.1)/LBASE
1500 THMX=ALPHA+THSTR-ATN(DUM6/SQR(-DUM6^2+1))
1510                       ' thmx: theta at check thickness = .1
1520 IF (TPEFF/LBASE+KTHETA*THMX/LBASE) > PMAX  THEN 2580
1530  PRINT "the detector will be modeled as a rigid beam with constant velocity
1540  PRINT "with a spring/damper included to model the deformation of the
1550  PRINT "document.  The values for the spring constant and damping ratio of
1560  PRINT "specific documents must be determined experimentally.
1570 KCHK=30:CCHK=.0001:GOTO 1650
1580  PRINT: PRINT "Input a reasonable value for the spring constant(approx 30 l
b/in)"
1590 INPUT KCHK
1600  PRINT: PRINT "Input a reasonable value for the damping coeff(approx .0001
lb-sec/in)"
1610 INPUT CCHK
1620  PRINT USING"weight = ##.##### lb";BWT
1630  PRINT USING"dist. from pivot to center of lower portion of beam = ##.#####
  in ";LCOG
1640  PRINT USING"mass moment of inertia = ###.#### in-lb-sec^2";IM
1650 PRINT USING "spring constant = ####.## lb/in  damping coefficient = #.#####
# lb-sec/in";KCHK,CCHK
1651 DIM VEL(1000)
1660 '
1670 ' ***************************************************************************
1680 ' ***** at initial impact, no motion will take place.  motion   **********
1690 ' ***** will begin when the force due to the check exceeds      **********
1700 ' ***** that of the spring (the preload).                       **********
1710 ' ***** look at the motion from impact to theta at check height **********
1720 ' *****                                                         **********
1730 ' ***** step 1: document in contact, no motion                  **********
1740 ' ***** solve for the time when the document force is greater   **********
1750 ' ***** than the effective preload.                             **********
1760 PRINT"step 1: document in contact, no motion                    "
1770 '
1780 TIME=0:THETA=0:HEIGHT=0:THDOT=0:VELOCITY=0
1790 IF DTYN <> 1 THEN 1810
1800 PRINT #1,TIME,HEIGHT
```

```
1810 TIME=(TPEFF/LSTR/COS(THLO)-CCHK*CVEL)/(KCHK*CVEL)
1820  PRINT USING"time for motion to begin (after impact) = ###.###### msec";TIM
E*1000
1830 ' ************************************************************************
1840 ' ***** step 2: document in contact, not higher than check ht.   **********
1850 PRINT"step 2: document in contact, not higher than check ht. "
1860 '
1870 ' find the relevant constants to be sent to the subroutine.
1880 TINC=.00002  :TM=0                 'time increment (sec)
1890 THZ=0:THDZ=0                              'theta and thetadot at t=0 are zero.
1900 XBAR=LUP^2/2*COS(THUP-THETA)+LLO*(LUP*COS(THUP-THETA)+LLO/2*COS(THSTR-THETA
))/(LUP+LLO)
1910 YBAR=LUP^2/2*SIN(THUP-THETA)+LLO*(LUP*SIN(THUP-THETA)+LLO/2*SIN(THSTR-THETA
))/(LUP+LLO)
1920 TWT=BWT*(XBAR^2+YBAR^2)^.5*COS(ATN(YBAR/XBAR))
1930 K1=(-TWT-TPEFF+(CCHK+KCHK*TIME)*CVEL*COS(THLO)*LSTR)/IM  'forcing function
1940 K2=(KCHK*CVEL*COS(THLO)*LSTR)/IM                     'forcing function:f(t)
1950 GOSUB 2610
1960 IF THETA > THCT THEN 2020
1980 IF DTYN <> 1 THEN 2000
1990 PRINT #1,TIME,HEIGHT
2000 TIME=TIME+TINC:TM=TM+TINC
2010 GOTO 1950
2020 ' ************************************************************************
2030 ' ***** step 3: document no longer in contact.                  **********
2040 PRINT"step 3: document no longer in contact.                    "
2050 '
2060 ' find the relevant constants to be sent to the subroutine.
2070 TM=0
2080 THZ=THETA:THDZ=THDOT     'theta and thetadot at t=0 are non-zero.
2090 XBAR=LUP^2/2*COS(THUP-THETA)+LLO*(LUP*COS(THUP-THETA)+LLO/2*COS(THSTR-THETA
))/(LUP+LLO)
2100 YBAR=LUP^2/2*SIN(THUP-THETA)+LLO*(LUP*SIN(THUP-THETA)+LLO/2*SIN(THSTR-THETA
))/(LUP+LLO)
2110 TWT=BWT*(XBAR^2+YBAR^2)^.5*COS(ATN(YBAR/XBAR))
2120 K1=(-TWT-TPEFF)/IM                'forcing function
2130 K2=0                         'forcing function:  f(t)
2140 GOSUB 2610
2150 IF THETA < THCT THEN 2210
2160 IF (VEL(III-2)*VEL(III-1) < 0) AND (HEIGHT > CTHK+.002) THEN PRINT USING "t
ime = ###.##### msec  height = ##.##### in";TIME*1000,HEIGHT
2170 IF DTYN <> 1 THEN 2190
2180 PRINT #1,TIME,HEIGHT
2190 TIME=TIME+TINC:TM=TM+TINC
2200 GOTO 2140
2210 ' ************************************************************************
2220 ' ***** step 4: bouncing begins                                 **********
2230 PRINT"step 4: bouncing begins                                   "
2240 '
2250 FOR I=1 TO 5                      'number of bounces
2260 ' find the relevant constants to be sent to the subroutine.
2270 TM=0
2280 THZ=THETA:THDZ=-THDOT*EE 'theta and thetadot at t=0 are non-zero.
2290 XBAR=LUP^2/2*COS(THUP-THETA)+LLO*(LUP*COS(THUP-THETA)+LLO/2*COS(THSTR-THETA
))/(LUP+LLO)
2300 YBAR=LUP^2/2*SIN(THUP-THETA)+LLO*(LUP*SIN(THUP-THETA)+LLO/2*SIN(THSTR-THETA
))/(LUP+LLO)
2310 TWT=BWT*(XBAR^2+YBAR^2)^.5*COS(ATN(YBAR/XBAR))
2320 K1=(-TWT-TPEFF)/IM                'forcing function
2330 K2=0                         'forcing function:  f(t)
2340 GOSUB 2610
2350 IF (TM > 5*TINC) AND (HEIGHT < CTHK-.000001) THEN 2410
2360 IF (VEL(III-2)*VEL(III-1) < 0) AND (HEIGHT > CTHK+.002) THEN PRINT USING "t
ime = ###.##### msec  height = ##.##### in";TIME*1000,HEIGHT
2370 IF DTYN <> 1 THEN 2390
2380 PRINT #1,TIME,HEIGHT
```

```
2390 TIME=TIME+TINC:TM=TM+TINC
2400 GOTO 2340
2410 NEXT I
2411 PRINT USING"maximum force = ###.###### lb    allowable force = ###.#####";(
TPEFF/LBASE+KTHETA*THMX/LBASE),PMAX
2412 PRINT USING"time = ###.##### msec";TIME *1000
2420 CLOSE 1
2470 IF DTYN <> 1 THEN END
2480 PRINT"check your data."
2490 PRINT"press CR to continue"
2500 INPUT ANY
2510 IF DTYN=1 THEN 2530
2520 INPUT "from what file do you wish the data to be listed";FLNM$
2530 OPEN FLNM$ FOR INPUT AS #1
2540 IF EOF(1) THEN END
2550 INPUT #1,A,B
2560 PRINT USING" ##.### MSEC  #.###### INCHES";A,B
2570 GOTO 2540
2580  PRINT"maximum force is greater than allowable force"
2590  PRINT USING"maximum force = ###.###### lb    allowable force = ###.#####";
(TPEFF/LBASE+KTHETA*THMX/LBASE),PMAX
2600 GOTO 1530
2610 '
2620 ' ************************************************************************
2630 ' ******** the following subroutine includes generalized equations ********
2640 ' ******** that describe the motion of the beam for every time     ********
2650 ' ******** increment involved in the dynamic response.             ********
2660 ' ******** diff. constants are sent to yield theta(t) & thdot(t)   ********
2670 ' ******** relevant constants: k1,k2,time,thz,thdz                 ********
2680 ' ******** k1: forcing function not a function of time            ********
2690 ' ******** k2: forcing function a function of time                ********
2700 ' ******** time: time offset                                       ********
2710 ' ******** thz: theta at time = zero                               ********
2720 ' ******** thdz: thetadot at time = zero                           ********
2730 '
2740 KK1=(K*K1-C*K2)/K^2
2750 KK2=-C/2*TM
2760 THETA=K2/K*TM
2770 THETA=THETA +KK1
2780 THETA=THETA+(THZ-KK1)*EXP(KK2)*COS(OMEGA*TM)
2790 THETA=THETA+(THDZ+C/2*THZ-C/2*KK1-K2/K)/OMEGA*EXP(KK2)*SIN(OMEGA*TM)
2800 THDOT=K2/K
2810 THDOT=THDOT-(THZ-KK1)*EXP(KK2)*OMEGA*SIN(OMEGA*TM)
2820 THDOT=THDOT-(THZ-KK1)*EXP(KK2)*C/2*COS(OMEGA*TM)
2830 THDOT=THDOT+(THDZ+C/2*THZ-C/2*KK1-K2/K)/OMEGA*EXP(KK2)*OMEGA*COS(OMEGA*TM)
2840 THDOT=THDOT-(THDZ+C/2*THZ-C/2*KK1-K2/K)/OMEGA*EXP(KK2)*C/2*SIN(OMEGA*TM)
2850 HEIGHT=HTOT-LBASE*SIN(THSTR-THETA+ALPHA)
2860 IF HEIGHT < 0 THEN HEIGHT = 0
2870 VELOCITY=THDOT*LBASE
2871 VEL(III)=VELOCITY
2872 III=III+1
2880 RETURN
```

VITA

David M. Melchers was born in Benton, Illinois on October 14, 1962. He attended elementary school in Chester, Illinois and graduated as salutatorian from Chester High School in May 1980. The following August he entered The University of Illinois at Urbana-Champaign. As an undergraduate, he published a paper on developmental biomechanics entitled "Measurement with an Elastimeter of the Stiffness of Epithelial Vesicles from Pupal Moth Eye" in Roux's Archives of Developmental Biology. In May 1984 he received a Bachelor of Science degree in Mechanical Engineering. In the summer of 1984, he attended The University of Maryland as a graduate special student while enrolled in a Leadership Training program in Washington, D.C.

In the fall of 1984, he accepted a graduate assistantship at The University of Illinois at Urbana-Champaign and continued study toward a Master's degree. Having a commission to move to Knoxville, he began work on his thesis project in March 1985 at The University of Tennessee, Knoxville. He received the Master of Science degree with a major in Mechanical Engineering in August 1986.

Mr. Melchers is currently employed by Impell Corporation in Knoxville.